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# GUIDELINES FOR CONDUCTING GROUND-WATER STUDIES IN SUPPORT OF RESOURCE PROGRAM ACTIVITIES

by

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This report is a technical reference document providing guidance on collecting, analyzing and interpreting ground water data. A methodology that utilizes two investigative levels for the systematic collection and analysis of ground water data is described. These levels are: Reconnaissance Level (Level I) and Comprehensive Level (Level II). Techniques of conducting each level of investigation are presented which include characterization of hydrogeology, ground water quality characterization, data collection procedures and graphical methods of presenting data. A separate section on conducting ground water contamination studies is also presented.

Several appendices provide additional supporting information. A complete annotated listing of legislative authorities and regulstions pertaining to ground water is included.

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TABLES



FIGURES

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GUIDELINES FOR CONDUCTING GROUND-WATER STUDIES
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## INTRODUCTION

Ground water is generally understood to be water occupying all the voids within a geologic stratum and which thus creates a zone of saturation. This zone is usually found below an unsaturated, or aeration zone in which the voids are filled with both air and water that extend upward to the surface of the ground, furnishing soil moisture. The boundary between these two zones is neither rigid nor impermeable and allows movement of water between the zones (for example, recharge of the ground water by percolation). Inasmuch as the water within the zone of saturation constitutes the major, less easily renewed part of the subsurface resource, the following discussion concerns only that zone.

Ground water, unlike other categories of commodities and energy and minerals resources, is not only intrinsically valuable but also vital in the use of other resources. Development of ground water may be prerequisite to the economic development of either energy or mineral resources on public lands managed by BLM.

Furthermore, ground water is also a commodity and a resource that is managed (appropriated) and protected by the State governments, yet can be beneficially or adversely affected by BLM management of public land (energy, minerals, and hazardous materials). These unique characteristics make it essential to integrate management of energy and mineral development/hazardous materials disposal with overall State authority.

The importance of ground water varies inversely with the availability of surface water of acceptable quantity and quality. The value may vary within a relatively small geographic area and over a relatively short period of time, depending upon the ability of surface sources to meet demand at acceptable costs. When no supply of surface water exists, even limited ground water is a critical resource.

Recognition of ground water's value has led to the enactment of protective legislation at both Federal and State level. Federal legislation includes the Safe Drinking Water Act (P.L. 93-523), the Resource Conservation and Recovery Act (P.L. 94-580), and the Surface Mining Control and Reclamation Act (SMCRA) (P.L. 95-87). While the laws of many States add additional environmental protection, a number of States also regulate the withdrawal and use of ground water for maximum benefit. BLM personnel involved with ground water must be fully knowledgeable about pertinent Federal and State legislation, policies, and regulations.

Determining the importance of ground water is difficult in many geographical areas, particularly as determinations of future value must be based on subjective projections of possible events. Similarly, even reasonably accurate projections of the effects of hydrologic stress are difficult, time-consuming, and frequently very costly. Except in the case

of simple decisions, lack of adequate data upon which to base decisions is the foremost problem. Possibly the most critical factor in predictive assessments concerning ground water is the recognized national deficiency in field expertise. The second major obstacle in assessing ground-water management issues is in determining what hydrogeologic data are available in a form land managers can readily understand and use. Making decisions about ground-water matters is hampered by the lack of adequate data, an acknowledged shortage of field expertise, and difficulty of presenting complex data in readily usable form.

## Purpose

The purpose of this document is to provide technical guidance within the framework of various legislative and regulatory mandates pertaining to ground water (see Appendix A), and BLM Planning system directives. One emphasis of this document is to provide guidance for evaluating ground-water resources on Federal lands involved with energy and mineral development or evaluating situations where ground-water contamination is of concern. However, the techniques outlined herein are applicable to any ground-water investigation.

The primary authority for the management of ground water lies with the individual States and their designated agencies. This guidance is issued to increase the awareness of Bureau personnel in basic ground-water interpretive techniques, and to provide a reference document for sources of information on ground-water resources relevant to BLM activities. An extensive appendix is provided, which contains useful supporting information or background material on various aspects of ground-water investigations.

These Guidelines are intended to provide guidance and assistance to line Managers, EIS team members, resource professionals and other BLM staff that must use hydrogeologic information or assist the professional hydrologist. They are a tool to be used by the hydrologist or geologist when working with other professionals and managers on ground-water projects, so that a common framework is available to the various offices involved.

This report assumes that users of these guidelines have an understanding of the fundamentals of ground-water flow and the geologic relationships that control ground-water occurrence. The report provides general guidance to Bureau personnel on the kinds of information needed to conduct ground-water investigations, and the minimum data requirements for various levels of investigations. The acquisition and use of hydrogeologic data from existing sources is emphasized. The report also provides guidance on data collection and interpretation requirements for intensive hydrogeologic studies which may require collection of new data. The methodology presented is meant to be applied to various resource program activities within BLM, primarily the Minerals Program and the Soil, Water and Air Program.

It is recommended that planning and implementation of the hydrogeologic analyses discussed in these guidelines include the services of a geologist familiar with the local geology, and that the study be closely supervised by

either a hydrologist or geologist experienced with hydrogeologic analyses. These guidelines are not intended to be used as a substitute for the services of a qualified hydrogeologist, hydrologist, or geologist.

This report is not intended to be a "how to" document which provides the explicit step-by-step details for conducting ground-water investigations. Several excellent treatises, texts, and research reports are available that provide detailed guidance on the various techniques outlined in this report. Reference materials categorized as "essential", "recommended" or "special topics for the interested reader", are listed in Appendix B. The "essential" references are those that provide outstanding instruction on hydrogeologic principles, contain unique insight into solving ground-water problems, or that contain useful summaries or descriptions of techniques in applied hydrogeology. These references are essential to having a minimum ground-water library, and should be acquired for use in any office where ground-water issues exist. The acquisition of these references will provide BLM personnel with sources of information for most general ground-water investigations. Site specific or process-specific investigations (such as heap leaching operations for gold) will need to be researched on a case-by-case basis.

The "recommended" references are those that contain useful, well written, informative treatises on hydrogeology or related topics, but are not considered essential to have in a basic ground-water library.

Other references listed as "special topics for the interested reader", are listed to provide a source of known particularly useful documents, as a starting point for specialized investigations.

The objectives of these guidelines are to:

* Identify the role of BLM and Federal legislation in relation to State legal authorities for the protection and study of ground-water resources.

* Develop technical guidelines for the collection, analysis, and interpretation of ground-water information

* Provide guidance to facilitate the prediction of potential effects on ground-water resources due to energy and mineral development, hazardous waste disposal, or other sources of ground-water contamination.

* Improve the coordination of Federal, State, and private ground-water collection programs and BLM activities, through increased awareness of ground-water issues and investigative techniques.

## Scope

Because of the nature of ground water and the uses placed upon it, both management decisions and protection requirements are especially important if any of the following conditions exist in an area:

* A significant ground-water basin or aquifer system exists.

* A principal or sole-source aquifer therein has been designated or is being considered for designation by a State or EPA program.

* Mining of coal, phosphate, uranium, or other leasable mineral.

* Mining of locatable minerals.

* Hazardous or toxic substances entering the ground-water system (e.g., through municipal land fills, surface spills, or designated hazardous waste sites) may potentially affect water users.

* Oil and gas or geothermal resource development.

* Heap leaching for gold (including old tailings).

Ground-water investigations are conducted in BLM for the following categories of activities:

Ground-Water Inventory and Analysis for Bureauwide Regional Programs or Special Studies--Ground-water data collected Bureauwide or regionally will often focus on a single ground-water issue or concern; for example, collection and analysis of data for a regional mineral ES (coal, oil shale); inventory and monitoring to assist the USGS in regional aquifer studies or investigations of potentially hazardous waste sites. Such broad studies often require Federal and State coordination to ensure complete technical review and economical studies. Federal and State cooperative data collection programs exist in most States and may provide data for land management decisions involving ground-water issues. A 1964 directive issued by the Office of Management and Budget (OMB), Circular A-67, establishes guidelines for Federal agencies to coordinate their activities in acquiring water data from "streams, lakes, reservoirs, estuaries, and ground water" (Office of Technology Assessment, 1984 p.83).

Ground-water Inventory and Analysis for Multiple Use Planning--Ground-water analyses will be based on known or anticipated planning issues. The level of detail will be dictated by the nature of the issues and level of acceptable risk.

Ground-Water Analysis for Activity Planning--Ground-water data in support of activity planning should build on existing data bases and be supplemented if necessary by collection of new data from the field. For example, a ground-water monitoring network could be the result of an activity plan.

## Procedure

The following guidelines should be followed when a ground-water study is being considered for implementation:

1. Consider the General Water Resources Policy Manuals and General Inventory Manuals

Guidance for the Water Resources program is contained in the 7200 series of Manuals. These Manuals are part of the Soil, Water, and Air Program that is described in Manual 7000.

Specific directives for water resources are found in the following Manuals: Water Resources (7200), Ground Water (7230), Water Quality (7240), and Water Rights (7250). These Manuals should be reviewed prior to initiating water resources studies. Other supporting documents for water resources such as handbooks and technical references, will be issued periodically as an adjunct to the 7200 Manual series.

Guidance on resource inventory and monitoring is contained in Manual 1734. These directives require coordination among the various resource programs within BLM to ensure effective and efficient multiple-use management of public lands. Guidance on general resource inventory procedures (in relation to the planning system) is also contained in Manual 1734.

2. Define the Study Objectives.

Evaluate alternative approaches to the study in order to avoid needless data collection. Realize that a ground-water study is often a dynamic process where study objectives need to be changed as data are gathered. Defining exact study objectives will usually provide insight into the problems. Initiating a study without fully evaluating all the possible interrelated aspects can lead to serious errors in study design.

3. Consider the Known Energy/Minerals Ground-Water Issues.

These may be associated with oil and gas development, geothermal development, mining, landfills, surface impoundments, and injection wells or other hazardous/toxic waste disposal methods. Representative examples include (a) leaching of contaminants through spoil piles downward into the ground-water systems, (b) migration of toxic materials associated with mining or oil and gas drilling that have been disposed of on the surface, (c) acid mine drainage, and (d) disruption of aquifers, especially sole-source aquifers as defined in Section 1424(e) of the Safe Drinking Water Act, (e) disposal of petroleum drilling fluids and byproducts, (f) geothermal effluent disposal, and (g) underground injection of wastes from a variety of production facilities, as appurtenances to leases.

4. Analyze the Adequacy of Existing Ground-Water Data.

Evaluate existing data to determine its adequacy to meet the needs of Bureauwide, regional, or special programs; multiple-use planning; and activity planning or monitoring. Document the presence or absence of pertinent ground-water data. Consider the date of collection and the relative utility of the ground-water data with respect to current legislation and issues.

5. Develop Data Collection or Analysis Requirements for Ground Water.

Submit these as part of the geology or soil, water, and air program proposal. Because deterioration in ground-water quality often is detected only after it is too late to prevent, awareness of water quality trends is essential to the planning or control process. However, data should not be collected without some defined objectives. Data collection (ground-water monitoring) must be conducted for specific purposes, such as to comply with Federal regulatory policy. Four types of monitoring are identified. These are: (1) ambient trend monitoring, (2) source monitoring, (3) case preparation monitoring (i.e., litigation), and (4) research monitoring (Everett 1980). Of these types, source monitoring is of primary importance. To BLM, source monitoring is at the forefront of many of the monitoring requirements of Federal legislation and regulations. Collection of baseline data is extremely important where ground-water contamination is suspected. Determination of the baseline or ambient water quality can help delineate ground-water pollution plumes, for example.

Ground-water monitoring requirements related to Federal Legislation (public laws), and regulations generally lack specificity; however, some Federal regulations contain detailed requirements to address specific problems. For example, the regulations developed under the Surface Mining Control and Reclamation Act (SMCRA) and Toxic Substances Control Act (TSCA) specify the minimum parameters that must be measured; the Resource Conservation and Recovery Act (RCRA) (Subtitle C), the Safe Drinking Water Act (SWA), SMCRA, and the Uranium Mill Tailings Radiation Control Act (UMTRCA) specify monitoring frequencies. In addition, the number of monitoring wells is specified in both the requirements for PCB disposal sites under TSCA and the interim status requirements under Subtitle C of RCRA. (Office of Technology Assessment, 1984, p.159)

6. Enter Data into Ground-water Data Base.

Information gathered during the ground-water investigation should be stored in a data management system which is designed specifically for ground-water data. The use of 3- by 5-in. cards designed for this purpose provides a convenient method to record field data on wells (see fig. 1). These cards are available from the Ground-Water Coordinator at the Denver Service Center. An existing data base (the Ground-Water Site Inventory file) on the BLM Honeywell computer provides a means of storing and retrieving data on both wells and springs. Contact the hydrogeologist at DSC for further information and assistance in loading data into the system.

Side 1

T. ____________

R. ____________

Sec. ____________

_____ ¼ ___¼___¼

State ____________ County ____________

District ____________

Area ____________

Map ____________

Series ____________

Altitude, in feet ± ________

________ Land surface

________ Water level

________ Bottom of hole

Depth of well ____________

Aquifer(s) ____________

Yield ____________

Temperature ____________

Conductivity ____________

pH ............ ________

**Water level measurements below top of casing**

| Depth to static level | Date |
|---|---|
| | |
| | |
| | |
| | |

| Depth to pumping level | Pumping rate in gpm | Date |
|---|---|---|
| | | |
| | | |

Specific capacity ____________

*(Over)*

Side 2

Date of record ____________ Record by ____________

Name of well ____________ Owner ____________

Topography ____________

Type and construction method ____________

Use ____________ Pump ____________ Power ____________

Casing size ____________ Type ____________ Height above ____________

Other information available [ ] Log [ ] Driller's record

[ ] QW analysis [ ] Other

Remarks ____________

*(Over)*

GPO 844-055

Figure 1. Water Well data field card.

## LEVELS OF INVESTIGATION

Decisions affecting lands containing potential energy and mineral resources must be based upon adequate levels of information to ensure that the merits and drawbacks of proposed actions can be examined with a suitable level of confidence.

Two levels of investigative methodology are used that describe the intensity of a particular ground-water inventory and analysis. These are: Reconnaissance Level of Knowledge (Level I) and Comprehensive Level of Knowledge (Level II). The level of analysis used for specific studies shall be determined by the risk the decision maker is willing to accept, and time and fiscal constraints.

Level I investigations concern primarily the collection and analysis of existing hydrogeologic data. This level permits decisions to be made with reasonable confidence, while providing a low cost investigation.

Detailed investigations (level II) usually require the collection of new information that may include (1) on-site monitoring, (2) special field study, or (3) computer modeling. These investigations, normally site-specific, concern complex issues of far-reaching significance or involve situations that present a threat to human health or the environment.

The objective of these two levels is to define the hydrogeologic situation. Level II is just a refinement of understanding about the ground-water flow system with additional study components added, such as contaminant transport or health effects of toxic chemicals. Research detail is governed by the availability of information and project scope.

Hydrogeologic studies require the integration of geologic, hydrologic, climatologic, and vegetative information. This information is used to formulate a "model" of the ground-water system. This is always a conceptual model at first, which may be refined into mathematical models later in an investigation.

In general, the collection and analysis of hydrogeologic data whether for Level I or II is conducted with the objective of obtaining the following information:

1. Aquifer locations, extent, depths, and thicknesses.
2. Hydraulic characteristics (transmissivity, permeability, storage coefficient, etc.)
3. Directions and velocities of ground-water flow.
4. Ground-water levels (maps of ground-water levels are the product).

5. Depths to ground water (maps produced from these data combined with topographic information).

6. Areas and magnitudes of ground-water recharge.

7. Areas and magnitudes of natural ground water.

8. Water quality of each aquifer .

9. Character of the ground-water system (i.e., whether aquifers are confined, unconfined; are fracture flow or porous media flow; or whether multiple aquifers are present).

10. Present use of ground-water in study area (locations, well depths, and magnitude of withdrawals).

11. Locations of potential ground-water contamination sites.

12. Geologic constraints to ground-water movement (faults, aquitards, formation changes).

## Using Existing Information

### Level I - Reconnaissance Level of Knowledge

A reconnaissance investigation is a relatively low cost evaluation of a large area and does not include field work except to evaluate the general geology of the project site and to correlate mapped geologic units with outcrops, noting surface features pertinent to ground water not shown on geologic maps such as: (1) fractures and joints; (2) erosional characteristics; (3) geologic features that might control ground-water flow and recharge; (4) surface expressions of ground-water movement, such as springs, seeps, landslides or slumping; and (5) general character of streams and valleys.

A reconnaissance investigation is applicable to broad studies of aquifers of District or Statewide scope. Information derived from this level provides insight into the design of more advanced levels of investigation which are more site specific. A Level I inventory would suffice when the proposed land use has no significant long-term effect on the quality or quantity of usable ground water. The land manager must ascertain whether the ultimate land use decision can be made with available information or requires more data. The issues unique to the area must then be considered.

Level I is characterized by these standard investigative techniques (modified from Peek, 1980):

1. Review geologic and ground-water literature on both regional and local hydrogeologic conditions.

2. Describe depths of wells and their yields.

3. Collect well records primarily from literature; augment these with records with records from the USGS WATSTORE data base (Ground-Water Site Inventory file) or State records.

4. Identify the principal aquifers and describe their thickness and extent.

5. Identify and describe aquifer characteristics (transmissivity, porosity, permeability, storativity).

6. Describe the ground-water quality for each of the aquifer units.

7. Estimate the general potential for ground-water development in the study area.

8. Identify gaps or anomalies in the data that may require further research.

9. Define general areas of recharge and discharge.

10. Identify major geologic controls affecting well yields (such as continuity of aquifers, faulting, fracturing, and joints)

11. Estimate water use, type, and number of users.

12. Describe range of water level fluctuations.

13. Prepare a water resource base map of the area utilizing all of the above information.

## Developing New Information

### Level II: Comprehensive Level of Knowledge

An investigation at the comprehensive Level provides more detailed information to fill data gaps identified during the Reconnaissance Level Investigation. The resulting document should utilize a comprehensive literature search to evaluate all available data to make decisions regarding land use. It should address potential site specific impacts to the ground-water regime. Depending on the complexity of the issues, some site evaluations may require investigative detail requiring new data collection or design of corrective action or monitoring programs. Generally, a Level II inventory will suffice when the proposed action may have significant medium or long-term effects on the quality or quantity of ground water.

Hydrogeologic systems analysis is a refinement of the Level II investigation, wherein the ground-water system and all its interrelated components are evaluated.

Level II is characterized by the following investigative procedures (modified from Peek, 1980):

1. Collect drillers' logs and well construction details of as many wells as possible.

2. Collect and analyze data from representative aquifer tests.

3. Estimate the potential development of the aquifer system, if this is a management issue.

4. Prepare water level contour maps and combine with sufficient data on geology and hydrology to develop an understanding of the hydrologic boundary conditions in the area.

5. Analyze water quality data of each aquifer or sub-unit.

6. Make integrated analysis of stream flow and ground-water records.

7. Identify and evaluate data on the stresses (pumpage) affecting the ground-water system. Identify existing and potential problems and provide solutions where possible.

8. Describe the effect of man's activities on ground-water quality (e.g., fertilizer uses in agricultural areas).

9. Provide management alternatives for ground-water development, protection, or corrective action.

10. Establish data requirements for ground-water quality or quantity management. This could include design of a ground-water monitoring program.

11. Develop conceptual model of ground-water flow system and describe hydrology and hydrogeology using all available information applicable to the problem.

12. Utilize numerical or analytical models to make predictions about the ground-water flow system or about contaminant transport processes.

13. Evaluate existing contamination sources.

## RECONNAISSANCE LEVEL (LEVEL I)

### Data Collection

Data collection for a reconnaissance investigation focuses on information that is easily available from existing records, reports, or maps. The initial objective is to define, with minimum resource expenditure, the hydrogeology or

the magnitude of ground-water contamination and the potential for legal action if the project could result in litigation. The review should be as thorough and accurate as possible, within the scope of the particular study. Preliminary background information collection should lead to:

1. Refinement of investigation objectives.
2. Identification of data needs to meet the refined objectives.
3. A plan for the site inspection and evaluation.
4. A resource data base for conducting subsequent project activities.

Literature Searches

The primary consideration in collecting data for the Reconnaissance Investigation is that they are easily obtainable, published materials.

The first step in a Level I investigations is to obtain all published geologic information on the study area from other Federal agencies, State geological surveys, or university sources. The data collection phase should begin with USGS literature, because USGS has the largest collection of hydrogeologic information. The review of USGS reports should include reports other than just water supply papers. Several other publications can provide helpful data or interpretations for ground-water investigations (e.g., open file reports, professional papers, bulletins, hydrologic atlases, geologic quadrangle maps, water resource investigations, and coal resource maps). Any of these USGS publications may provide information related to hydrogeology of the study area. Hydrologic atlases, geologic maps, geologic quadrangle maps, and water-supply papers should be especially helpful. The hydrologic atlases are the most useful because they usually provide interpretations of hydrogeologic data, which often include graphical presentations (see Appendix C for specific sources of hydrogeologic information).

Literature searches using computerized bibliographic information retrieval systems are recommended. These systems are available from commercial vendors, and are accessed via a computer terminal to log-on to the data base. Searches are made using any word in the title or abstract. Recent advances in search capabilities of the systems now provide for searching the full text of the journal article for the desired keyword. Some data bases will also print out the full text of the selected journal article. Searches can also be made for words adjacent to each other, or for two words separated by several other words.

There are several data bases available that contain literature sources that would be useful in the conduct of hydrogeologic investigations. Requests should be made to the library staff at the Denver Service Center giving key words relating to the ground-water system and location of the study area. The library staff can then provide a comprehensive print-out of available literature that serves as a foundation for in-depth surveys. (See Appendix D for a listing of bibliographic data bases useful for hydrogeologic investigations.)

When an investigation begins, relevant data types and sources are seldom known; consequently, a variety of subject areas must be evaluated in regard to the study site to select appropriate research requirements. Four major subject areas are discussed here as beginning points for information gathering: (a) geology, (b) hydrology, (c) hydrogeology, and (d) contaminants.

## Geology

Relevant geologic information includes regional and site specific data pertaining to both consolidated (bedrock) and unconsolidated formations. Those factors that affect water movement and quality are most important. If nothing is known about the geologic setting of the site, research stratigraphy first. If other geologic factors are of concern, stratigraphic information is likely to provide clues as to which are important. For example, if stratigraphy is complex due to faults and folds, "structural features" would be an appropriate subject to research. If certain formations are found to contain abundant lead-bearing minerals, then "mineral resources" should be researched. Judgment is exercised to determine the extent of information gathered in any subject area.

Site geology is often expressed in the surface topography as land forms because geologic structure is a dominant control factor in their evolution. After identifying geologic features, plot them on the topographic map so the geologic setting can be related to observable land forms. These land forms will be evaluated during the site visit (if required), regarding their potential to control surface and/or subsurface water flow.

Many State geological surveys or State water resources agencies have cooperative agreements with the USGS and other Federal agencies to carry out field investigations. These offices, as well as the USGS District Offices, are good sources of detailed information for their jurisdiction. (See Appendix E for a list of state geological surveys)

## Hydrology

Discharge of springs and streams: The flow of springs and streams reflects ground-water conditions and geology. In consolidated rocks, the location and alignment of springs are related to the location of faults or other structures influencing water accumulation; and the flows indicate the presence of aquifers. Springs may be caused by bodies of perched ground water, water under artesian pressure, or outcrops of the main water table. Gains or losses in base flow of streams mark reaches affected by ground-water discharge or recharge.

Estimates of flows may suffice for preliminary surveys, but measurements are needed for detailed investigations. The U.S. Geological Survey measures the flow of most streams and many springs; discharge records are published.

For field estimates of flows, use the equation Q=AV (where Q=flow, A = cross-sectional area of the stream channel, and V=velocity of flow). Techniques are outlined in Water Supply Paper 2175 (Rantz and others, 1982). For a definitive discussion of measuring stream flow, see Herschy, 1985. Also, see U.S. Bureau of Reclamation, 1981.

## Hydrogeology

Hydrogeologic investigations are the process for collecting and analyzing information on the occurrence and movement of ground water, and the behavior of contaminants in the flow system. This knowledge is obtained primarily by collecting and analyzing data on the hydrogeologic environment (to ascertain the rate and direction of ground-water flow to help predict contaminant behavior) and on ground-water quality (to ascertain the presence and concentrations of contaminants) (office of Technology Assessment, 1984, p.112) Knowledge of contaminant properties is also helpful; for example, in determining how fast contaminants move relative to ground-water flow, if they rise to the upper zone of the aquifer, or they sink to the bottom, and move along the base of the aquifer.

Water-level measurements are important basic preliminary data often used in selecting ground-water sampling sites, equipment, and procedures. Water-level data can be obtained from wells, piezometers, or from surface water manifestations of the ground-water system such as springs, lakes, and streams. The depth to water may determine the type of pumps or samplers used and procedures and cost of constructing monitoring wells. Water-level contours drawn from static levels in wells penetrating the same aquifer can be used to make a preliminary determination of gross direction of flow. Note that nearby pumping wells or other artificial discharges or recharges may alter the natural gradient (Scalf et al., 1981, p. 5-6)

Information pertaining to specific well locations, well construction details, and well logs may be obtained from the State Engineer, USGS, and other agencies. In addition, in-house information such as project files, well site reports, and the Central File (Code 7200 series) may be reviewed. Requests may be made to the USGS or the Ground-Water Coordinator at DSC for individual well data from the Ground-Water Site Inventory (GWSI) file of WATSTORE (see Appendix F for list of state agencies for ground-water management and protection; also, see Appendix G for computer-based state and sub-state data bases).

Estimating ground-water quantity requires the following data: (1) static water levels, (2) aquifer thickness, (3) areal extent of aquifers, (4) well construction information (i.e, does the well fully or only partially penetrate the aquifer, and what is the screened interval?), and (5) coefficient of permeability.

## Contaminants

Advances during the last decade in techniques for analyzing water quality samples--for identifying increasing numbers of specific substances, for detecting substances at progressively smaller concentrations, and for

increasing the automation of instrumentation--have been major driving forces behind the detection of contaminants in ground water. Continued improvement is expected; not only will previous undetected substances be found but more will be detected at increasingly small concentrations (Office of Technology Assessment, 1984, p. 127).

Not all contaminants, however, can be detected at low concentrations using routinely available techniques. Further, the fact that certain substances can be measured at increasingly small concentrations does not mean that they need to be. Rather, analysis should be guided by the levels at which substances may cause serious threats to human health or welfare. Major unresolved issues concern which substances and concentrations to measure, given limited resources, in order to evaluate the risks to public health and to provide the public with confidence that it is being protected (Office of Technology Assessment, 1984, p.127-128).

At present, techniques for measuring substances in ground water are not being used consistently, and they introduce a bias in terms of which of the substances present are detected. In addition, analytical accuracy becomes increasingly difficult to achieve as concentrations become very small and mixtures become more complex (Office of Technology Assessment, 1984, p.127).

Ground-Water Data Retrieval

The National Water Data Exchange.--The National Water Data Exchange (NAWDEX) Program Office of the USGS maintains two computerized data bases which serve as central indexes of data available Nationwide. They are the Water Data Sources Directory (WDSD), and the Master Water Data Index (MWDI).

(1) Water Data Sources Directory. The Water Data Sources Directory (WDSD) is a computerized data base that contains information about organizations that are sources of water and water-related data and services, members of NAWDEX, and are active in programs relevant to the water resources community. For each organization, WDSD identifies the type of organization; its major program orientation; the names, addresses, and telephone numbers of its major offices and field locations; types of data held by the organizations and the geographic locations in which the data have been collected; alternate sources of an organization's data; types of water-related data collected by the organization; and textual comments concerning the organization's activities, systems, and services. Currently, over 600 organizations have been registered in the WDSD, and new organizations are added on a continuing basis. While only minimal information currently exists for many organizations registered in the data base, the NAWDEX Program Office maintains a continuing data-gathering program to improve the information available on data-source organizations.

(2) Master Water Data Index. The Master Water Data Index (MWDI) is a computerized data base that contains information about sites for which water data are available (Perry and Lewis, 1978). It contains information on the identification of the organization collecting data at the site; identification and geographic location of each site; type of data-collection site (stream,

lake, well, etc.); current status of the site; types of data available; period of time for which data are available; major water-data parameters for which data are available; frequency at which parameters are measured; and the media in which data are available. Currently, MWDI contains information for over 189,000 surface water sites and over 116,000 ground-water sites at which data are, or have been, collected by almost 400 organizations. Additional information is added to the MWDI on a continuing basis. Computerized interfaces have been developed between two major water data systems--the National Water Data Storage and Retrieval System (WATSTORE) of the USGS, and the Storage and Retrieval (STORET) system of the U.S. Environmental Protection Agency. A third interface is under development between MWDI and the Texas Natural Resources Information System (TNRIS), and others will be developed as resources permit. The computerized interfaces allow for the annual updating of water data stored in the systems by over 60 organizations.

The WDSD and MWDI serve as central indexes for acquiring information concerning water and water-related data available from a large number of organizations at a single source. The two data bases contain common identifiers that allow them to be used in conjunction with each other. For example, MWDI may be used to identify sites for which data are available within a geographic area, and WDSD can be used to obtain the addresses of offices from which the data may be obtained.

The data bases may be queried by geographic locations identified by latitude-longitude vertices, State and county codes, and hydrologic regions; general types of data required (stream flow, water quality, etc.); specific types of data (biologic, chemical, sediment, etc.); and many other criteria. Information can be provided from the data bases in a variety of printed reports formatted to the user's request, in the form of statistical summaries, and by site-location map-plot overlays at a variety of scales.

Most NAWDEX Assistance Centers have access to the data files of the USGS's WATSTORE system for data retrieval and dissemination purposes. In addition, the retrieval and dissemination of data contained in the U.S. Environmental Protection Agency's STORET system is provided as a service by the NAWDEX Program Office in Reston, Virginia, and the Assistance Center facilities provided by the Texas Natural Resources Information (TNRIS) in Austin, Texas.

Water Data Storage and Retrieval System (WATSTORE).--The USGS, through its Water Resources Division, is a major collector of water data in the Federal sector. It investigates the occurrence, quantity, quality, distribution, and movement of the surface and underground waters that comprise the water resources of the United States. As a part of the USGS's program of releasing water data to the public, the National Water Data Storage and Retrieval (WATSTORE) system was developed to provide more effective and efficient management of the Survey's data-releasing activities.

The WATSTORE system provides for the processing, storage, and retrieval of water data pertaining to surface water, water quality, and ground water. The system consists of five files as described below:

1. Station Header File. This file contains information pertinent to the identification, location, and physical description of over 200,000 sites located nationally for which data are stored in the WATSTORE files.

2. Daily Values File. This file contains water-data parameters measured or observed daily or on a continuous basis and numerically reduced to daily values. Instantaneous measurements at fixed-time intervals, daily mean values, and statistics such as daily maximum and minimum values may be stored. The file currently contains over 186 million daily values, including data for stream flow values, river stages, reservoir contents, water temperatures, specific conductance values, sediment concentrations, sediment discharges, and ground-water levels.

3. Water Quality File. This file contains data pertaining to the chemical, physical, biological, and radiochemical properties of both surface and ground waters. Currently, the file contains the results of over 1.4 million analyses of water samples and almost 200 different constituents. Data contained in the file are also entered into the STORET system of the U.S. Environmental Protection Agency.

4. Peak Flow File. This file contains annual maximum (peak) stream flows (discharge) and annual maximum gage height (stage) values obtained at surface water sites. It currently contains more than 400,000 annual maximum observations.

5. Ground-Water Site Inventory File. This file contains inventory data about wells, springs, and other sources of ground water. These data include site location and identification, geohydrologic characteristics, well construction history, and one-time field measurements such as water temperature and water level. It currently contains information for over 6,000,000 wells.

Data contained in WATSTORE may be obtained in the form of computer printed tables, computer printed graphs, statistical analyses, digital plots, and machine readable formats. WATSTORE services may be obtained from any of the Assistance Centers of the National Water Data Exchange (NAWDEX) (Edwards, 1980).

<u>EPA'S Storage and Retrieval System (STORET)</u>.--STORET is made up of three files: (1) water quality file, (2) flow data file, and (3) the fish kill file. The water quality file is the largest of the STORET files, and is the most frequently used. About 1800 unique water quality parameters are defined in STORET. About 80% of the observations available in the system pertain to approximately 200 of these paremeters. The parameters are grouped into the following general categories:

1. Radiological
2. Phosphorous
3. Pesticides
4. Flow
5. Biological
6. Bacteriological
8. Nitrogen
9. Oxygen demand
10. General organics
11. Dissolved oxygen
12. Metals
13. Physical

### Base Map Compilation

The following items should comprise the minimum water resource base map at the reconnaissance level of investigation:

1. Indicate surficial geology and outcrops of subsurface units that serve as aquifers.

2. Indicate spring locations and their flow rates.

3. Plot representative well locations.

4. Present associated well data in tabular form:
   a. Depth of well ("as built" and present condition).
   b. Depth of water (Note seasonal and historical changes).
   c. Well yield (date of measurement and method used to measure yield).
   d. Name of producing formation and the interval screened or perforated (in feet below the surface) if available.
   e. Water use.
   f. Date and time of measurement.
   g. Elevation of ground surface at well.
   h. Time since most recent pumping.
   i. Casing dimensions.
   j. Screen material and size.
   k. Method used to seal annulus of well.
   l. Date drilled.
   m. Drilling method.
   n. Total dissolved solids.
   o. Casing material.
   p. Method of completion (development).
   q. General physical condition of well.

5. Delineate areas of recharge and discharge. Indicate general flow directions if water level contour maps are available.

## HYDROGEOLOGIC CHARACTERIZATION

### Techniques of Investigation

Characterization of hydrogeologic conditions requires the use of a variety of techniques. Methods of assessing hydrogeologic conditions range from sophisticated geophysical techniques to geological mapping. The application of every technique during an investigation would not normally be needed except for evaluating waste sites that are extremely toxic and pose a threat to human health through ground-water contamination.

Ground-water flow can be readily described in most environments; however, information cannot be readily obtained on the physical, chemical, and biological processes that may cause contaminant attenuation. This difference reflects both the state of scientific understanding and available technology. For example, mechanisms of ground-water flow are better understood and mathematical modeling of flow is more highly developed than for contaminant behavior; thus data can be interpreted more reliably, and more accurate predictions can be made for ground-water flow than for contaminant behavior (Office of Technology Assessment, 1984, p. 118).

Techniques used to describe the hydrogeologic environment and to collect ground-water quality samples are organized into 12 major categories in Table 1. The table outlines the general types of information obtained and the limitations of the techniques under different conditions.

The following descriptions are for Table 1 (Office of Technology Assessment, 1984, p. 118):

Information Obtained. Regardless of what techniques are used, which parameters are measured, and whether the measurements are taken directly or indirectly, all measurements must be interpreted in conjunction with other data to determine ground-water flow and the behavior of contaminants. Interpretation of data is uncertain because of factors relating to: the precision, accuracy, or detection limits of the equipment; lack of a unique measurement (e.g., geophysical response) for particular subsurface conditions; the degree to which averaging of conditions masks actual conditions; and the degree to which the sample or the measurement represents in-situ phenomena.

Techniques are generally available to collect data on the unsaturated zone, ground-water hydrology, sources, and contaminants; this information is necessary to make reliable predictions of ground-water flow and estimate current and future water quality in most environments. However, historic data and data reflecting changes with time (e.g. ground-water use and the contaminant release characteristics of sources) are usually not available for a specific site, which diminishes the reliability of some investigations.

Constraints. Factors that can limit the use of different techniques are related primarily to site conditions, costs, and the availability of skilled personnel. Additional constraints include problems with property access and the potential for adverse effects.

Table 1. Techniques for hydrogeologic investigations: Information obtained and principal constraints. (From: Office of Technology Assessment, 1984)

| Techniques | Information | Major site contraints | | | | Other constraints |
|---|---|---|---|---|---|---|
| | | Subsurface geology | Subsurface hydrology | Water quality | Surface conditions | |
| 1. Unpublished and published information | To identify geologic, hydrologic, hydrogeologic, water quality, topographic, and climatic conditions. | Type of geologic formation: May not be sufficiently detailed for complex geologic settings. | Complexity of subsurface conditions: Usually data are unavailable for specific sites, but some regional hydrogeologic information may be useful, particularly in simple, uniform hydrogeologic settings. | Not a constraint. | Not a constraint. | Proprietary data may limit availability. |
| 2. Mapping | To delineate surface geologic, soil, or topographic conditions. | Not a constraint. | Not a constraint. | Not a constraint. | Site access: Inaccessible terrain may be problematic during ground surveys. | Nonsite-specific information often adequate; represents separate cost. May require a relatively long time to complete (days to months). |
| 3. Remote sensing (aerial photography and thermal, infrared, and radar satellite imagery) | To assess indirectly geologic, hydrologic, hydrogeologic, or water quality characteristics of the earth's surface. A reconnaissance tool to optimize surface field studies. | Depth: Techniques generally provide information on only face features but some techniques may provide some information on shallow groundwater flow and/or contaminant seepage within 10 feet of the land surface.<br>Type of geologic formation: Some techniques can penetrate the surface and provide information on contaminants if under thin alluvium or sand. | Saturation conditions: Some techniques (e.g., radar) to detect presence of contamination are applicable only in unsaturated areas where there is a moisture difference between contaminated and uncontaminated areas.<br>Flow system: Detectable contamination limited to discharge areas with techniques other than radar. | Nature of Chemical Compounds: Contaminant distribution can be detected by various techniques if chemicals stress vegetation, cause tonal changes in surface water, or thermal anomalies. | Climate: Some techniques are weather dependent; cloud cover interferes with all techniques except radar.<br>Timing: Some techniques are accomplished best at different times of day (e.g., predawn or midday) and seasons. | Nonsite-specific information often adequate; represents separate cost. |
| 4. Excavations and drilling | To access directly the subsurface environment for the purpose of geologic sampling, geophysical logging, water quality sampling, and fluid potential measurements. | Depth: Excavations generally only done at less than 20 feet. Applicability of different drilling techniques varies with depth; however, with use of proper equipment, holes can be drilled to virtually any depth.<br>Type of geologic formation: Some drilling techniques can be used in only certain types of materials (soil versus rock, consolidated versus unconsolidated, prone to caving versus non-caving). | Not a constraint. | Nature of chemical compounds: Presence of certain contaminants may limit use of some drilling fluids to avoid sample contamination. Variations in contamination with depth may limit use of certain techniques to avoid cross-contamination. | Scale: Excavations can cover larger areas than drilling.<br>Site access: It may be difficult to reach some sites (e.g., steep or marshy) with steep or marshy) with some types of equipment. | Property access: May require a relatively long time to complete (days to months). Relatively high cost to implement. |

Table 1. Techniques for hydrogeologic investigations: Informaton obtained and principal constraints (continued). (From: Office of Technology Assessment, 1984)

| Techniques | Information | Major site contraints: Subsurface geology | Subsurface hydrology | Water quality | Surface conditions | Other constraints |
|---|---|---|---|---|---|---|
| 5. Geologic sampling | To identify directly stratigraphy and geologic structure and to obtain geologic samples for laboratory testing of hydraulic and soil characteristics. | Depth: Type of sample that can be obtained depends on the depth and penetration capability of drill rig and/or sampling equipment. Depth is not a limiting factor for obtaining either undisturbed samples from some unconsolidated materials, or representative and non-representative samples from any type of materials.[b] Type of geologic formation: Some limitations depending on whether consolidated or unconsolidated. See Depth. | Not a constraint. | Not a constraint. | Not a constraint. | May require a relatively long time to complete (days to months) |
| 6. Hydrometeorological measurements | To quantify temperature, precipitation, evapotranspiration, and infiltration at the earth's surface. | Not a constraint. | Not a constraint. | Not a constraint. | Not a constraint. | Field techniques to measure transpiration are difficult to apply, so estimates are usually made. Nonsite-specific information often adequate; represents separate cost. |
| 7. Surface hydrology (hydraulic measurements; surface water sampling) | To identify flow and water quality characteristics of surface water. | Not a constraint. | Not a conatraint. | Nature of chemical compounds: Difficult to obtain samples of many organic compounds that are only slightly water-soluble. | Not a constraint. | Nonsite-specific information often adequate; represents separate cost. |
| 8. Subsurface Hydrology a. Potential measurements | To measure subsurface water level or pressure for evaluating direction of flow and to calculate flow rates within and between hydrologic units in both the unsaturated and saturated zones. | Depth: Depth is a limiting factor for some techniquea (e.g., some tensiometers and drill stem tests). However, techniques are available to obtain measurements at any depth, provided specially designed wells are drilled. Type of geologic formation: Fine-grained, low permeability material limits the use of certain techniques (e.g., standpipes). However, | Saturation conditions: Choice of techniques depends on whether measurement is required for the saturated or unsaturated zone. | Not a constraint. | Not a constraint. | Not a constraint. |

Table 1. Techniques for hydrogeologic investigations: Information obtained and principal constraints (continued). (From: Office of Technology Assessment, 1984)

| | | Major site contraints | | | | |
|---|---|---|---|---|---|---|
| Techniques | Information | Subsurface geology | Subsurface hydrology | Water quality | Surface conditions | Other constraints |
| a. Potential measurements (cont'd) | | techniques are available to obtain measurements in any type of formation provided specially designed wells are drilled. | | | | |
| b. Hydraulic testing | To determine the hydraulic properties of in-situ subsurface materials needed for calculations of flow rates in the unsaturated zones or directly measure groundwater flow velocities and to determine contaminant transport parameters. | Type of geologic formation: Some unsaturated zone techniques (e.g., infiltration tests) are impractical in coarse-grained soils due to the amount of water required. Choice of techniques (e.g., slug test, pressure injection test, and pump test) for saturated zone dependent on permeability of formation. | Complexity of subsurface conditions: Some techniques (e.g., slug tests and flow meters) measure conditions only at or near the point of measurement, and do not account for spatial heterogeneities. Saturation conditions: Some techniques are applicable in either saturated or unsaturated zones. | Not a constraint. | Not a constraint. | Relatively high equipment cost; intensive manpower requirements; and need for skilled personnel. May cause short-term changes in water levels. Tracers may have adverse environmental effects. |
| c. Laboratory testing (hydraulic, geologic) | To measure the hydraulic properties of samples of subsurface materials needed for groundwater flow calculations of variably saturated materials (e.g., porosity) and selected contaminant transport parameters (e.g., adsorption). | Depth: Testing dependent on obtaining appropriate type of sample (i.e., undisturbed, representative, or non-representative). Type of geologic formation: Depends on whether consolidated or unconsolidated. See Depth. Provides good method of measuring permeability of fine-grained unconsolidated materials. Choice of geologic sampling technique (hydrometer v. sieve tests) depends on grain size. | Complexity of subsurface conditions: Superior to field measurements of vertical permeability of fine-grained unconsolidated materials. Major limitation is small sample size and the applicability of extrapolating point information to the three dimensional space being assessed. | Not a constraint. | Not a constraint. | Not a constraint. |
| d. Water quality sampling | To obtain a subsurface water sample representative of in-situ water quality for analyses of the presence and concentrations of chemicals and other substances in unsaturated and saturated zones. | Depth: Some pumps to evacuate wells and obtain samples have depth limitations. Type of geologic formation: In high permeability formations, evacuation of sampling wells to ensure sample is not affected by the well is problematic. However, techniques are available to minimize the amount of pumpage required | Complexity of subsurface conditions: Multiple completion wells to characterize vertical distribution of water quality are limited due to concerns about the effectiveness of sealing to prevent hydraulic connections and the ability to obtain representative samples from different sampling zones. Saturation conditions: Different techniques are used to obtain samples in the unsaturated zone | Nature of chemical compounds: Casing, well materials, and pumps must be selected both to resist deterioration from long-term exposure to natural chemicals or contaminants and to minimize interference with the measurement of specific constituents. Current knowledge of sampling interferences is limited for most well materials. | Not a constraint. | Not a constraint. |

Table 1. Techniques for hydrogeologic investigations: Information obtained and principal constraints (continued). (From: Office of Technology Assessment, 1984)

| Techniques | Information | Major site contraints | | | | Other constraints |
|---|---|---|---|---|---|---|
| | | Subsurface geology | Subsurface hydrology | Water quality | Surface conditions | |
| d. Water quality sampling (cont'd) | | before sample collection, which may in turn limit selection of the most effective sampling equipment for particular constituents. | | Design constraints of multiple completion wells (e.g., small diameter) may may limit use of most effective sampling equipment for some chemical parameters. Proper disposal of evacuation water prior to sampling is dependent on its quality. Techniques used to evacuate wells and obtain samples may result in incorrect measures of some compounds (especially dissolved gases and volatile organics). Also, the presence of some constituents (e.g., sediment) may damage some types of equipment. Some techniques allow excessive exposure to the atmosphere or other gases that might influence the measurement of specific parameters. | | |
| 9. Hydrogeologic system analysis (modeling; geostatistics) | To simulate or predict the behavior of subsurface hydrogeologic units, including groundwater flow and solute transport; or to estimate the values of hydrogeologic phenomena at unmeasured points. | Not a constraint. | Complexity of subsurface conditions: choice of modeling technique (i.e., analytic or numeric) depends on complexity of problem. Modeling complex systems limited by cost of obtaining data. Most geostatistical methods require that the sample population be normally distributed; thus if data represent complex subsurface conditions, geostatistical methods may be difficult or impossible to apply. | Not a constraint. | Not a constraint. | Relatively high cost to implement. May require a relatively long time to complete (weeks to months). Specialized skills required. Requires a clear definition of the hydrogeologic parameters used, including their variability in time and space. |
| 10. Surface geophysics (electrical resistivity and electromagnetic conductivity; ground-penetrating radar; seismic refraction; shallow geothermic method) | To assess indirectly stratigraphy and extent of subsurface contamination to aid in placement of monitoring well sand to reduce number of wells. | Depth: Depth limitations are dependent on technique. Generally, techniques cannot be applied at depths greater than 500 feet. Type of geologic formation: Minimum detecta- | Complexity of subsurface conditions: Techniques applicable only in relatively simple stratigraphic conditions. Natural subsurface properties must be sufficiently uniform so as not to confuse or mask the effects of chemicals. Natural | Nature of chemical compounds: Chemicals of interest must be capable of both inducing a change in the subsurface parameter measured by the method and showing a different response than | Climate: Some techniques requiring electrode contact not applicable in frozen soils or in dry sandy areas (e.g., electrical conductivity). However, other techniques are applicable in these | Relatively high equipment cost; need for skilled personnel; may require a relatively long time to complete (weeks to months). |

Table 1. Techniques for hydrogeologic investigaitons: Information obtained and principal constraints (continued). (From: Office of Technology Assessment)

| Techniques | Information | Major site constraints | | | | Other constraints |
|---|---|---|---|---|---|---|
| | | Subsurface geology | Subsurface hydrology | Water quality | Surface conditions | |
| 10. Surface geophysics (cont'd) | | ble concentration strongly influenced by properties of subsurface materials. Conditions that may prevent good results include: naturally conductive brackish water, steep water table, crystalline rock, and karst or other environs where ground-water flow is concentrated along interconnected fractures in massive bedrock. | conditions that may be responsible for false detection or nondetection include: discontinous, thick layers of clay; hydrogeologic heterogeneity; variations in natural ground-water chemistry due to changes in geologic materials; and variations in surface topography. Some methods are more effective than others for detecting small fracture zones containing high contaminant concentrations (e.g., electromagnetic conductivity is better than electrical resistivity). Homogeneous subsurface environments having layers of increasing densities present interpretative difficulties for some techniques (e.g., seismic refraction). All techniques generally require subsurface drilling or monitoring for verification of results. Saturation conditions: Some techniques can be used to obtain some types of information only in the unsaturated zone (e.g., electrical resistivity can track contaminant movement in only the unsaturated zone). | surrounding subsurface conditions. Many techniques (e.g., resistivity and conductivity methods) generally are ineffective for defining organic contaminant plumes. However, the presence of organic chemicals and petroleum products may be delineated in sand or gravel aquifers at depths generally less than 25 feet with ground penetrating radar. Relatively high concentrations required by techniques for detection of contaminants. Techniques only provide gross information on concentrations of some individual constituents. Some techniques can be effective in delineating extent of high concentrations of inorganic contamination in suitable geologic environments. | conditions (e.g., electromagnetic conductivity). Nature of surface: Conductors (e.g., metal fences, overhead power lines, paved areas, buildings, storage tanks, and buried pipelines or wires) may impair use of some techniques. Sensitivity of different techniques to these features is variable. Bare rock, wetlands, shallow lakes, and dry sandy areas prevent use of techniques requiring electrode contact. | |
| 11. Subsurface (borehole) geophysics (acoustical; electrical-magnetic; nuclear; flow; thermal; geochemical) | To measure direct physical properties of subsurface materials to evaluate lithology, geologic structure, hydraulic properties, water quality, and flow. | Depth: Not a limiting factor for most techniques provided an uncased borehole can be drilled. Type of geologic formation: Most techniques can be used only in uncased boreholes, and thus cannot be used in geologic formations that cave in when drilled. Exceptions include nuclear logs which can be used in cased boreholes. Some tech- | Saturation conditions: Some techniques (e.g., electrical-magnetic logging techniques) are applicable only in saturated zone. Some techniques can be used to provide certain types of information in the unsaturated zone, and other types of information in the saturated zone (e.g., neutron logs). | Nature of chemical compounds. Some techniques applicable only if constituents in ground-water have properties that will induce response from instruments (e.g., spontaneous potential logs). Some techniques can be used to detect particular contaminants (e.g., Draeger tubes can detect over 140 in-situ soil gases). | Not a constraint. | Relatively high cost to implement. |

Table 1. Techniques for hydrogeologic investigations: Information obtained and principal constraints (continued). (From: Office of Technology Assessment, 1984)

| Techniques | Information | Major site contraints: Subsurface geology | Subsurface hydrology | Water quality | Surface conditions | Other constraints |
|---|---|---|---|---|---|---|
| 11. Subsurface (cont'd) | | niques more suitable for obtaining information on particular types of geologic materials (e.g., natural gamma logs for obtaining clay unit properties). | | | | |
| 12. Hydrogeochemistry | To perform field testing of water samples to determine need for further laboratory chemical analysis and to analyze for unstable consituents. | Not a constraint. | Not a constraint. | Nature of chemical compounds: Field techniques available to obtain information on conductance, organic vapors, alkalinity, pH, Eh, DO, iron, and hydrocarbons. (See Subsurface Hydrology — Groundwater quality sampling, for additional constraints.) | Not a constraint. | Not a constraint. |

[a]Based on Geotrans, Inc., 1983b.
[b]*Undisturbed sample*—An in-place specimen in which features such as structure, density, and moisture content are essentially preserved. Suitable for laboratory testing of properties of geologic structure.
*Representative sample*—A disturbed sample in which some features do not survive but grain size and gradation are preserved. Suitable for grain size gradation analyses and obtaining knowledge of subsurface stratigraphy.
*Nonrepresentative sample*—A sample that may consist only of drill cuttings or other incomplete or contaminated portions of subsurface materials. Generally not suitable for testing or analysis. Somewhat suitable for subsurface stratigraphy.

Site conditions that can limit the use of hydrogeologic techniques include: subsurface geology (e.g., depth and type of geologic formation); subsurface hydrogeology (e.g., complexity of subsurface conditions, saturation conditions, and flow system); water quality (e.g., nature of the contaminants), and surface conditions (e.g., presence of buildings, pavement, power lines, vegetative cover, and other features; site accessibility; climatic factors; time of day; and size of the area).

As shown in Table 1, site constraints on obtaining information vary for different categories of hydrogeologic techniques as well as for specific techniques within each category (e.g., climate is a constraint only on certain remote sensing and surface geophysical techniques). Some techniques are limited to particular subsurface conditions (e.g., different techniques are used for the saturated zone than for the unsaturated zone). In addition, the site constraints that apply to a particular technique vary, depending on the purpose for which the technique is used (e.g., subsurface geology constraints on geologic sampling depend on the type of sample that is needed).

## Interpreting Geologic and Hydrologic Data

Defining the ground-water system requires the collection and interpretaion of data from a wide variety of sources. Complexity in ground-water systems is most often the case. Several factors must be evaluated for possible influence on the ground-water system. In situations of ground-water contamination, the complexities of chemical reactions and dispersion are superimposed on the ground-water flow system. The resulting system can thus become very expensive and time consuming to investigate.

To facilitate hydrogeologic investigations, a summary of various sources of geologic and hydrologic information applicable to the purpose of our assessments is presented in Tables 2 and 3.

Table 2. Types and sources of geologic information

| Topic | Definition and Sources |
|---|---|
| Stratigraphy | Stratigraphic data are formational designations, age, thickness, areal extent, composition, sequence, and correlations. Aquifers and confining formations are identified so that units likely to transport pollutants can be delineated. Lateral changes in formations (facies change) are noted if present. Information can be obtained from the USGS library and from major State university libraries, in addition to sources mentioned previously. Contact the DSC librarian for interlibrary loans from the USGS or other libraries. |
| Structural Features | Structural features include folds, faults, joints/fractures, and interconnected voids (i.e., caves and lava tubes). Deformed, inclined, or broken rock formations can control topography, surface drainage, and ground-water recharge and flow. Joints and fractures are commonly major avenues of water transport and usually occur in parallel sets. Solution features such as enlarged joints, sinkholes, and caves are common in limestone rocks and promote rapid ground-water movement. Pertinent data on structural features would include type, compass orientation, dip direction and angle, and stratigraphy. |
| Mineral Resources | Mineral resources refer to commercial deposits of minerals, quarry rock, sand/gravel, oil and gas. Such deposits near the study area are identified and located. These may represent pollutant sources to be considered when planning a sampling survey. Mines and quarries can often be used for direct examination of otherwise unexposed subsurface materials. USGS topographic maps show most mines/quarries and oil fields. Aerial photographs and ground level pictures from USGS studies can be helpful in identifying and locating these features. County soil surveys published by the U.S. Department of Agriculture are useful because they are printed as overlays on aerial photographs. They are available through State conservation offices. |
| Seismic Activity | In active seismic zones, disposal site covers and liners may prematurely fail due to earth movement along faults. For this reason, fault locations and the seismic history of the study area are determined. The State geological survey is recommended as the first source to check when seeking this type of information. |

Table 2. Types and sources of geologic information (continued)

| Topic | Definition and Sources |
| --- | --- |
| Formation Origins | Information about the origin of a deposit or formation (i.e., volcanic, metamorphic, stream-laid, etc.) gives clues to the hydrogeologist about structure, grain-size distribution (laterally and vertically), weathering, and permeabilities. |
| Weathering Profile | Bedrock and unconsolidated deposits, such as glacial till and windblown loess, develop characteristic weathering profiles. Zones in those profiles may be more permeable than others. The zones should be identified and characterized by composition and thickness. Weathering profiles for shallow depths (less than 10 ft) are usually presented in county soil survey maps. |
| Grain-size Distributions | Grain-size analysis, conducted on samples from unconsolidated formations, yields the proportion of material for a specified size range. Range distributions can be used to estimate permeabilities, design monitoring wells and enable the hydrologist to better interpret stratigraphy. Such analyses are most often performed during pre-construction engineering/soils studies for a site and may be obtained from local consulting firms in addition to other sources mentioned previously. |

Table 3. Types and sources of hydrologic information

| Topic | Definition and Sources |
|---|---|
| Surface Drainage | Surface drainage information includes tributary relationships, stream widths, depths, channel elevations, and flow data. The nearest permanent gaging station and period of record should also be determined. A USGS 71/2 minute topographic map will show some of the necessary information. Gaging stations and flow data can be identified and obtained through USGS data bases (Appendix C) |
| Ground and Surface Water Relationships | Streams near hazardous waste sites(HWSs) can either receive ground-water inflow or lose water by channel exfiltration. Hydrologic literature is reviewed to determine if local streams are "gaining" or "losing". Losing streams are common in areas of limestone bedrock and those with arid climates and coarse-grained channel substrates. |
| | Potential ground-water recharge areas are also identified. Flat areas or depressions noted on the topographic are suspect, while steep slopes normally promote runoff. Stereo-pair aerial photographs can be useful in these determinations. Irrigated fields detected in aerial photographs suggest recharge areas; swampy, wet areas suggest areas of ground-water discharge. |
| Underlying Aquifers | Information is collected to delineate aquifer type (unconfined, confined, or perched), composition, boundaries, hydraulic properties (permeability, porosity, transmissivity, etc.), and interconnection with other aquifers (direction of leakage). These data are generally available through geological survey publications. |
| Depth to Ground water | As used here, depth to ground water refers to the vertical distance from the ground surface to the standing water level in a well. In a confined aquifer, the depth to water represents a point on a "piezometric" surface. The depths will limit the types of equipment that can be used for purging and sampling. Probable ground-water flow directions (both horizontal and vertical) are determined by comparing depths to water adjusted for estimated ground surface elevation. |

Table 3. Types and sources of hydrologic information (continued)

| Topic | Definition and Sources |
|---|---|
| Water/Waste Contact | Possible ways that water could contact wastes are researched to understand how pollutants are carried into the environment and for later consideration in designing remedial measures. Possibilities include:<br>1. Precipitation falling directly on wastes<br>2. Precipitation infiltrating through cover materials<br>3. Floodwater (determine flood frequencies and elevations, compare to waste elevation)<br>4. Ground water (compare elevations of wastes and ground water) |
| Water Quality | The quality of ground and surface water in an area will define, to a large extent, potential uses. Leachate from an HWS can degrade water quality to the extent that practical uses is limited or terminated. Knowledge of natural or background water quality and water uses are required to assess leachate imports. Data on quality of surface waters is usually available from EPA, USGS, and State records. |

Report Criteria

In summary, the following reporting techniques will result in characterization of hydrogeology:

1. Identify geologic units and lithology.
2. Describe the aquifer thickness, saturated thickness, and areal extent.
3. Indicate the porosity and permeability for each unit.
4. Discuss confined and unconfined aquifers, addressing the following:

    a. Confined aquifers:

        (1) Describe the depth to water to characterize aquifer conditions. Note the producing formation. Indicate the interval screened or penetrated (consult well records, drillers' logs) because evaluating confined aquifers on the basis of water levels alone can be misleading. This information may be hard to come by and must be tempered by knowledge of the local geology.

        (2) Determine if wells drilled in the aquifer would be artesian and flowing or artesian but not flowing. Both situations can occur in the same aquifer depending on the position of the land surface with respect to the potentiometric surface. See diagram of ground-water system relationships (Figure 2).

        (3) Indicate transmissivity and storativity in order to assess ground-water development potential of the area, or the effects of heavy hydrologic stresses (as in mining). Remember fluctuations in these parameters represent changes in hydraulic head. If the water level data for a confined aquifer is from wells, be sure that the well is a true piezometer, only open to the aquifer at the intake. Determine these factors from the existing literature.

    b. Unconfined aquifers:

        (1) Describe the relationship of the water table level to the land surface.

        (2) Indicate the transmissivity of the aquifer. Although this parameter is not as well defined as in a confined aquifer, it still may be useful.

        (3) Indicate the specific yield of the aquifer. This storage term is the same as storativity for confined aquifers although specific yield values are much higher. This means that compared to confined aquifers, the same yield can be realized with smaller head changes over less extensive areas. Walton (1970) presents techniques for defining hydrogeologic characteristics.

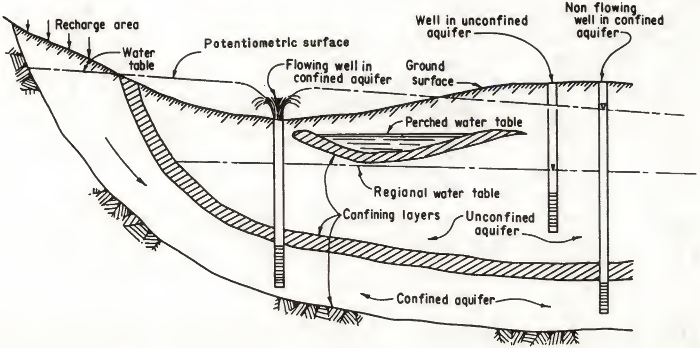



Figure 2. Ground water system relationships (From U.S. Bureau of Reclamation).

5. Describe the relationships of structure and stratigraphy to ground-water movement and storage; that is, qualitatively describe the aquifer system. For example, aquifers in the Wasatch Formation near a coal project could be described as follows:

> These units are quite variable, and can be good to very poor aquifers. There are many paleochannels where relatively permeable sandstones transmit enough water for successful water wells. Elsewhere, numerous clay layers can effectively perch water. These layers make it very difficult to describe regional aquifer characteristics. The thickness of the Wasatch Formation ranges from near zero in the coal outcrop regions to approximately 300 feet at the western edge of the study area.
>
> Numerous small stock wells have openings in these strata, and most water level maps of the area reflect the effects of gradients established by local drainages. In addition to rainfall infiltration, the units may be recharged by water in alluvial channels in the western part of the study area, and by water transmitted through clinker-overburden contacts. Most wells in the Wasatch are low yield stock wells, but wells which penetrate sandstone strata might produce up to 100 gpm. The percentage of the total discharge attributable to extraction from wells is not known, although it might be significant. (Everett, 1979, p. 112)

6. Assess Ground-Water Development Potential

a. Estimate well yields for undrilled or sparsely drilled areas.

(1) Interpretations of potential well yields based on lithology alone can be very misleading. Such estimates are usually at the following order of magnitude (Davis and DeWeist, 1966):

Metamorphic and plutonic rocks- - - - - - - - - - - - 10 to 25 gpm
Fine-grained sedimentary rocks- - - - - - - - - - less than 5 gpm
Sandstones- - - - - - - - - - - - - - - - - - - - - - - - 5 to 200 gpm
Limestones sometimes yield more than 200 gpm, but
more commonly yield- - - - - - - - - - - - - - - - - - 5 to 25 gpm
River deposits-
(thin deposits from small streams)- - - - - - - - - 10 to 50 gpm

(2) Larger yields, 100 to 200 gpm, may come from alluvial aquifers where the permeable zone is at least 10 feet thick, and the saturated zone is at least 40 feet thick. Yields of greater than 1000 gpm are not uncommon for alluvial wells where there is sufficient saturated thickness (Fetter, 1980).

b. Determine the specific capacity of wells or the well yield per unit of drawdown as gal/min/ft of drawdown. This parameter is often more descriptive of the aquifer system than yields (see Fetter, 1980).

c. Assess capability of the aquifer system to supply water for various uses.

d. Evaluate water level data. Water level data should be tempered with a knowledge of other limiting factors such as structure, stratigraphy, and recharge-discharge areas. Reliance should be placed on already published interpretive analysis; however, if no information is available, inferences may be drawn from data from nearby areas with similar rock types and structural conditions. Make it clear in the report that the data are not site specific.

## GROUND-WATER QUALITY CHARACTERIZATION

Level I interpretation is limited to use of existing interpretations plus a presentation of water quality problems identified. Determine the reason for particular water quality problems--for example, natural chemical interaction with rocks rather than man-introduced pollutants. Prepare Stiff diagrams and interpret any trends thereby disclosed.

At Level I, interpretations will be limited, inasmuch as graphs, charts or diagrams of water quality are not usually developed from raw data. Maximum use should be made of previously developed interpretation tools.

Indicate, on the base map(s), potential problem areas. Relate potential pollution to recharge areas--for example, surface disposal of mining waste or oil field brines can affect ground-water quality several miles away by infiltrating the saturated zone.

### Ground-Water Quality Criteria

All ground water contains dissolved solids, consisting primarily of a group of constituents referred to as major ions. These ions are sodium ($NA^+$), potassium ($K^+$), calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), chloride ($Cl^-$), bicarbonate ($HCO_3^-$), and sulfate ($SO_4^=$). Ground water that contains less than 1,000 mg/l of dissolved solids is referred to as fresh. If the dissolved solids range from 1,000 to 3,000 mg/l, the water is slightly brackish; if the range is 3,000 to 10,000 mg/l, the water is brackish. Saline water has dissolved solids in the range of 10,000 to 50,000 mg/l, and brine water has dissolved solids above 50,000 mg/l. (Seawater has approximately 35,000 mg/l of dissolved solids.) Uncontaminated fresh ground water is normally suitable for human consumption, for livestock, and for most industrial uses. Slightly brackish water may not be suitable for those uses, depending on the relative amounts of the various major ions and trace elements. Brackish, saline, and brine waters are never suitable for human consumption. In some cases, brackish water can be used for livestock, although saline and brine waters never can (Nat. Acad. of Sci., 1981).

In addition to the major ions, all ground water contains a large number of minor and trace constituents. The minor constituents occur in concentrations that are normally less than the major-ion concentrations and greater than the trace constituents. A common minor constituent, for example, is silica ($SiO_2$), which normally occurs in the range of 2 to 20 mg/l. Silica is of no consequence with regard to suitability for consumption by humans or livestock. The amount of dissolved iron (Fe), another minor constituent, depends on the oxidation status of the iron and can occur at levels of a milligram per liter to tens of milligrams per liter. In water with pH levels above 8, carbonate ($CO_3^{2-}$) may also exist in this concentration range. In ground water unaffected by man's activities, nitrate ($NO_3^-$) rarely occurs at levels above a fraction of a milligram per liter; because of the influence of agriculture and disposal of sewage on land, however, shallow ground water in some regions in which coal mining occurs contains $NO_3^-$ at levels ranging from one milligram per liter or tens of milligrams per liter. Water with more than 45 mg/l of $NO_3^-$ is unfit for human consumption (Nat. Acad. of Sci., 1981).

The trace elements most relevant to mining and water quality are those for which maximum permissible limits generally are specified in drinking water standards. Included are arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver. Although natural ground water usually contains trace elements at levels below the limits considered safe for drinking water, there are some exceptions. In assessing the effect of mining activities on ground water, the chemical composition of the existing ground-water systems should be well documented prior to mining. (National Acad. of Sci., 1981).

## Organic Compounds

All of the chemical constituents mentioned thus far are inorganic elements or compounds. Ground water naturally contains organic compounds, the total amount of which is normally expressed as dissolved organic carbon (DOC). Uncontaminated ground water generally contains between 1 and 20 mg/l of DOC, although in some areas where coal occurs, values in the range of 20 to 50 mg/l of DOC are observed. Natural DOC can cause water to have a slightly yellow or brownish color, but no limit on DOC is specified in drinking water standards.

However, an organic constituent that can occur naturally in ground water and for which maximum permissible limits generally are specified for drinking water is phenol. Phenol refers to a class of compounds in which one or more hydrogen atoms in an aromatic nucleus have been replaced by a hydroxyl group (OH). It is a constituent of the tars of both coal and wood. Natural phenol can occur in ground water at concentration levels considered unsafe for drinking water, but few data exist on phenol concentrations in existing or potential coal-mining areas.

## Water Quality Standards

The Environmental Protection Agency (EPA) has published the National Interim Drinking Water Standards (Fed. Register, v. 40, no. 2248, December 24, 1975). These regulations establish the maximum contaminant levels (MCLs) for numerous constituents (inorganic as well as organic) and some bacteriological standards. These standards apply to drinking water for human consumption. (BLM Manual 7240 addresses water quality related to Bureau programs.)

The MCLs are divided into (1) primary standards, which are maximum permissible standards, and (2) secondary standards, which are advisable maximum levels of contaminants.

Primary (mandatory) standards:

| | |
|---|---|
| Arsenic - - - - - - - - - - | 0.05 mg/l |
| Barium - - - - - - - - - - | 1.0 mg/l |
| Cadmium - - - - - - - - - - | .010 mg/l |
| Chromium - - - - - - - - - | .05 mg/l |
| Lead - - - - - - - - - - - | .05 mg/l |
| Mercury - - - - - - - - - - | .002 mg/l |
| Nitrate (as nitrogen) - - | 10.00 mg/l |
| Selenium - - - - - - - - - | .01 mg/l |
| Silver - - - - - - - - - - | .05 mg/l |

Secondary (advisable) standards:

| | |
|---|---|
| Chloride - - - - - - - | 250 mg/l |
| Color - - - - - - - - - | 15 Color units |
| Copper - - - - - - - - | 1 mg/l |
| Corrosivity - - - - - - | Noncorrosive |
| Foaming agents - - - - | 0.5 mg/l |
| Hydrogen sulfide - - - | 0.5 mg/l |
| Odor - - - - - - - - - | 3 Threshold odor number |
| pH - - - - - - - - - - - | 6.5-8.5 |
| Sulfate - - - - - - - - | 250 mg/l |
| TDS - - - - - - - - - - | 500 mg/l |
| Zinc - - - - - - - - - - | 5 mg/l |

Water quality data presented should represent the entire ground-water system. For example, several constituents will have a range of values, and these should be listed. This range gives a "fingerprint' of water quality for a specific aquifer in a specific location. Some chemical or biological constituents may be anomalous (either above or near the MCL and these should be presented in their entirety. In addition, comparison with the U.S. Environmental Protection Agency's drinking water standards (MCLs) or standards for other uses (livestock uses, recreation, and so forth) indicates the degree of magnitude of degradation of water quality. Present these data on maps and/or in tables (Hem, 1970); McKee and Wolf, 1963; National Academy of Sciences, 1972; and EPA, (1976).

In the case of landfill leachates, the typical ranges of inorganic contaminants can be compared to water quality standards or to the laboratory analysis of a specific site to evaluate the degree of contamination (see Table 4).

### Effect of Mining

Mining generally affects ground-water quality by changing the concentrations of dissolved compounds in the water rather than by adding new constituents to it. The changes are caused by a release of the compounds from geological materials disrupted by mining. The release results from (1) an increase in the surface areas of geological materials exposed to chemically aggressive subsurface water; (2) an increase in the chemical aggressiveness of circulating subsurface water, often because of the presence of oxygen; and (3) an increase in the rate of recharge or circulation of subsurface water (National Resource Council, 1981).

## COMPREHENSIVE LEVEL (Level II)

### Data Collection

Comprehensive investigations of grund-water systems might require the gathering of new data. Ground water monitoring may be needed in special situations to characterize the ground-water system. Ground water modeling would be used at this level to further refine understanding of the ground-water system, or to predict the response of the system.

If the hydrogeologic analysis is applicable to mining-related issues or to ground-water contamination, consultation with the Ground-Water Coordinator at the Denver Service Center, the Geology and Mineral Resources staff at the Washington Office, or specialists in other agencies is recommended prior to conducting any detailed investigations.

The literature search for Level II uses many of the same data bases as for Level I, but refinements in the computer search can be made because of greater knowledge of the problem. The following kinds of investigations should be conducted in order to provide an exhaustive survey of available literature and data:

1. Review the literature search to identify gaps in coverage. This presumes a clear understanding of what hydrogeologic problems might exist, or what problem is to be solved. Review the available data bases (Appendix D ) and conduct literature searches on those that can provide sources of specialized information.

2. Review bibliographies contained in reports pertaining to the specific problem to design your computer search for more specific information. Contact the librarian at DSC for assistance in selecting special data bases in which to make additional computer searches.

3. Review geologic maps, cross-sections, isopach maps, well logs, borehole geophysical data, and chemical data.

Table 4. Representative ranges for various inorganic constituents in leachate from sanitary landfills

| Parameter | Representative range (mg/l) |
|---|---|
| $K^+$ | 200-1000 |
| $Na^+$ | 200-1200 |
| $Ca^{2+}$ | 100-3000 |
| $Mg^+$ | 100-1500 |
| $Cl^-$ | 300-3000 |
| $SO_4^{2-}$ | 10-1000 |
| Alkalinity | 500-10,000 |
| Fe (total) | 1-1000 |
| Mn | 0.01-100 |
| Cu | < 10 |
| Ni | 0.01-1 |
| Zn | 0.1-100 |
| Pb | < 5 |
| Hg | < 0.2 |
| $NO_3^-$ | 0.1-10 |
| $NH_4^+$ | 10-1000 |
| P as $PO_4$ | 1-100 |
| Organic nitrogen | 10-1000 |
| Total dissolved organic carbon | 200-30,000 |
| COD (chemical oxidation demand) | 1000-90,000 |
| Total dissolved solids | 5000-40,000 |
| pH | 4-8 |

Source: Freeze and Cherry (1979, p.435)

4. Review soils information. This is important for evaluation of potential sanitary landfill sites, surface impoundments, or potential mine waste disposal sites.

5. Make personal contacts--The State Engineer's Office may have information on specific wells. Well logs that provide data on intervals of water production (depths) and rates of flow may be available. Personally contacting the State Water Resources Agencies for information on localized studies is recommended. Many State ground-water issues are identical or similar to BLM problems and studies done by State agencies may provide useful input for BLM's planning system or for site specific studies. Consult local universities about any pertinent studies. Consult USGS personnel about unpublished data that may be available for inspection. Authors usually have a few copies of their reports available if none are accessible through libraries. Consult agencies such as the Bureau of Reclamation, Water Conservation Districts, and State or County planning agencies.

6. Conduct field inventory or reconnaissance--Some of the well data gathered during the literature review may be old information or insufficient to meet the needs of the survey; consequently, some field verification of water levels and well yields may be necessary. The following items should be included in the field reconnaissance:

a. Springs and Seeps--Springs and seeps represent ground-water discharge and are generally a result of the water table intersecting the land surface or of leakage from an artesian aquifer. Locate any such feature on the site map and describe both the physical characteristics of the flow (i.e., color and odor) and the materials from which it emanates. Determine the discharge flow rate directly if possible.

b. Bedrock Outcrops--Locate bedrock outcrops on the site map, record the physical dimensions, and identify the rock type. Also measure major joint trends and formational strike and dip (if discernible) with a pocket transit. Methods of measurement are presented in Compton (1967). If field identification is not possible, collect samples of each rock type, label properly, and photograph the outcrop. Proper labeling involves recording in a logbook the vertical position, the section, and keying the information to a sample tag affixed to the specimen and/or sample bag.

c. Water-Level Data--Water level information is probably the most easily obtainable and most useful field data that can easily supplement existing data for Level II. However, to be usable, this information must be tied to the total depth of the well. Preferably, water level data would be tied to the specific depth for the screened interval. Data are usually only available from the driller's log or the record of well construction. This information can be used to generate water-level contour maps, water-level decline maps, and direction of ground-water flow maps.

On-site or nearby water supply wells are potential ground-water monitoring points. These potential monitoring points should be identified in case the study evolves into a more detailed evaluation, or if unexpected ground-water problems develop. Collect available construction information about any well identified during the site inspection.

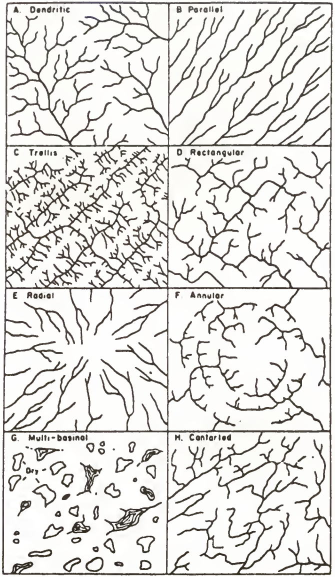
For techniques in measuring shallow wells, see U.S. Bureau of Reclamation (1981) and Anderson (1977). For techniques in measuring water levels in deep wells (deeper than 1,000 feet only), see Garber and Koopman (1968).

7. Interpret aerial photographs of study area. Use of low altitude (1:24,000) air photos is recommended for observation of topography and drainage patterns that may provide clues to the geologic structure governing ground-water occurrence and movement. Analysis of drainage patterns can provide information on hydrogeology not available elsewhere. For example, drainage patterns may indicate joints or fractures that could control ground-water flow, and they can indicate general rock types (see Fig. 3). Photogeologic analysis may provide the only method to evaluate hydrogeology. This situation occurs when existing geologic mapping is of a very small scale, rendering the map unsuitable for detailed analyses or the map has been found to be unreliable. (See Appendix H for information on sources of aerial photography.)

8. Utilize Aquifer Pumping Test information. One of the most important, practical problems in ground-water hydrology is the prediction of long-term yield from data gathered during short-period aquifer tests (Heath, 1983, p.58). The science of ground-water hydrology focused on these kinds of problems until the early 1970s, when concerns about the transport and fate of contaminants became the dominant theme of research and development, in ground-water science.

Quantitative aquifer characteristics should be determined to the maximum extent possible using existing aquifer test data. Because of the cost, difficulty, and amount of time involved, aquifer tests are seldom run in a Level II investigation. If no data are available for a specific area, an aquifer test may be run using existing wells, even if the locations are not ideal. If the test well is completed in the same geologic that information is needed, and no ground-water barriers exist (faults, stratigraphic and lithologic changes), extrapolate the results to acquire data for the desired site. Recognize that such extrapolation is risky, requiring several assumptions concerning the hydrodynamics of the system.

Aquifer testing usually involves one or preferably more observation wells located some distance from the pumped well. Such testing provides useful information about the storage capacity and transmissivity of the aquifer, but is expensive to conduct, even using existing wells and observation holes.




A. Dendritic occurs on rocks of uniform resistance to erosion and on gentle regional slopes.

B. Parallel occurs on steep regional slopes.

C. Trellis occurs in areas of folded rocks with major divides formed along outcrops of resistant rocks and valleys on easily eroded rocks.

D. Rectangular occurs in areas where joints and faults intersect at right angle.

E. Radial occurs on flanks of domes and volcanoes where there is no effect of differing rock resistance.

F. Annular occurs on eroded structural domes and basins, where resistant outcrops form major divides and weak rocks form valleys (a concentric type of trellis pattern).

G. Multi-basinal occurs in areas where the original drainage pattern has been disrupted by glaciation, recent volcanism, limestone solution, or permafrost.

H. Contorted occurs in areas of complex geology where dikes veins, faults or metamorphic rocks control the pattern.
The fishhook patern of the main stream might also result from capture of a northeast flowing stream by the southward flowing main stream.

Figure 3. Forms of drainage patterns resulting from various rock types.

Single well aquifer tests may also be made, using the production well without any observation wells. Tests using a single well (the one being pumped) reduce the cost and simplify the interpretation. Such information, though less definitive of the aquifer than when observation wells are used, does permit a good approximation of an aquifer's character. The information gained from a single-well test is the specific capacity of the well. Specific capacity is the discharge of the well Q, divided by the drawdown in the well, s. This is a good index of the capacity of the well to yield water; units of measure are in gal/min/ft of drawdown. The calculation of specific capacity is an excellent method to predict long-term yield. (Table 5 gives a summary of the various techniques being used for aquifer tests.)

## Ground-Water Monitoring

### Ground-Water Quality Sampling

Hydrogeologic investigations involve collecting information about the hydrogeologic environment and water quality at selected locations and then making assumptions about what is likely to be occurring between sampling points. In general, the more the sampling points, the less uncertainty is associated with interpretation of what is taking place in the subsurface; however, in hydrogeologic environments, changes in conditions can occur in a very short distance. Hence, knowledge of the geologic framework is essential to designing a sampling network.

Practical considerations limit the number of measurements taken. The number of measuring points (for direct techniques), the density of measurements (for indirect techniques), and the verification that is required to obtain a satisfactory level of confidence in the results depend on site conditions and the objective of the investigation. (Office of Technology Assessment, 1984, p.134)

To account for horizontal and vertical variations in the hydrogeologic environment and in water quality, both the location of sampling points and sampling frequency will vary depending on site conditions and objectives. For example, measuring points could be located at random or in an evenly spaced pattern or in relation either to the pathways of substances (i.e., measuring points are located where substances are either expected and/or not expected to be found) or to concentrations (i.e., measuring points are located where concentrations are highest and/or lowest). Sampling could be conducted once, annually, seasonally, or more frequently, depending for example, on whether ground-water flow patterns change periodically.(Office of Technology Assessment, 1984, p. 134)

A comprehensive search of existing water quality data should suffice for Level II investigations, but in some cases there may be a critical need for collecting new water quality data. This may be due to the following factors: (1) existing data may not be current, (2) data may not be available for the specific area under consideration, or (3) existing water

Table 5. Summary of aquifer test methods

| Test | Reference | Major Items Required | Parameters Obtained | Comments |
|---|---|---|---|---|
| Pumping | USDI 1977; Lohman 1972, Stallman 1971; Walton 1962; Ferris & Knowles 1963; Ferris et al. 1962 | Minimum of one observation well and preferably 4 or more; pump; power source; winch; tripod, mast or boom; discharge measuring device; stop watch; water level sounder | T, K, S | Yields parameter values averaged over a relatively large aquifer volume; most commonly used when accuracy and reliability is of high priority; best results in aquifers with good continuity and permeability provided by intergranular flow channels; can provide evidence of leakage through aquitards, directional permeability, and the presence of hydrogeologic boundaries. Relatively expensive, doesn't work well in very tight aquifers, requires a power source. |
| Drawdown/ specific capacity | USDI 1977; Lohman 1977; Walton 1970. | Same as above, but no observation wells are required. | T, K | Yields only rough estimates of T and/or K; storage coefficient or apparent specific yield must be estimated independently; conditions immediately adjacent to the well bore, well losses, etc., substantially affect results; in tight aquifers the effects of well-bore storage may be highly important. Relatively inexpensive; most useful in reconnaissance investigations. |
| Gravity injection | Same as above. | Supply of water (water truck or tank), injection hose or tubing, in-line flow meter, water-level measuring device, stop watch | T, K | Can be conducted on cased or open holes using the same equations as those for tests described above; conducted with constant head or with constant injection rate; best applications are with clean wells in poorly transmissive materials |
| Pressure pump-in | USDI 1977. | Inflatable or compression packers; pump; power source; pressure gages; stop watch; in-line discharge measuring device; storage capacity and source for water. | T, K | Usually conducted during exploration or reconnaissance investigations; permits determination of T and K in different intervals along the well bore; can be used above or below the water table or water level in the well; works best in consolidated aquifers or perforated well casing. Relatively expensive because it is usually conducted during the drilling operations using the contractor's rig and equipment. |
| Auger hole | Boast & Kirtham 1971. | Small pump or bail; stop watch; float | K | Applicable in cases of unconfined aquifers when the water table is within a few feet of ground surface; inexpensive, rapid, reliable |
| Recovery after any of the above tests. | Same as for test. | Same as for test. | T, K, S | Recovery should always be monitored following a drawdown/specific capacity test; usually yields more reliable values for T and K than the drawdown/ specific capacity test; has the additional advantage of providing an estimate of storage coefficient or apparent specific yield; because the rate of recovery is dependent upon the preceding pumping rate the results are effected by well-bore storage. Minimum expense in addition to that incurred during the pumping period and provides additional and more reliable information than the drawdown/specific capacity test. |
| Slug/falling head recovery | USDI 1977; Lohman 1972; Ferris & Knowles 1963; Kvorslev 1951; Covack & Papadopulos 1967; Bouver 1978 | Equipment required depends upon the manner in which the slug is added or removed. Pump may be used but it is not required. | T, K | A specific type of recovery test; one of the simplest and least expensive of all tests; does not require a power source; yields values acceptably accurate for most purposes; analysis procedures available that account for aquifer storage only, well-bore storage only, or both. Applicable in both confined and unconfined aquifers. |

*T = transmissivity, K = hydraulic conductivity, S = storage coefficient or specific yield

Source: National Acadamy of Sciences, 1981, p. 159

quality data do not include the constituents of concern in the current study. Before conducting ground-water sampling, the following preliminary investigations must be completed (these data are necessary in order to properly design a ground-water sampling strategy):

1. Define hydrogeologic situation.
2. Define ground-water usage in study area, and vicinity.
3. Identify potential pollutants and their possible behavior within the ground-water flow system.
4. Assess existing ground-water quality.
5. Evaluate mobility and attenuation of pollutants.

To keep costs to a minimum, select wells for sampling which will sample aquifers that have insufficient data. Determine which water-quality parameters are most important to the study, and sample in accordance with the techniques outlined in Chapter 2 of the Handbook on Recommended Methods for Water Data Acquisition (USGS, 1980b). Samples should be sent to a water quality testing lab certified by EPA for analysis. (see Appendix I for a list of EPA quality assurance coordinators who can supply information on certified labs for your area).

The success of a ground-water monitoring program depends on numerous factors; however, the design and construction of the monitoring wells are usually the most costly and non-repeatable factors. Hence, it is extremely important that the well construction be accomplished properly at the outset.

The primary objectives of monitoring wells are:

1. to provide access to ground water.
2. to determine which pollutants are present in the ground water and the concentrations.
3. to determine the areal and vertical distribution of pollutants.

In order to accomplish these objectives in the most competent and cost-effective manner, consideration must be given the proper well design and construction method that will best fit the specific objectives and the hydrogeologic conditions. For information on monitoring well design, see Everett, et al.(1976), Voytek (1983), Rinaldo-Lee (1983), and Scalf, et al. (1981).

<u>Location of Monitoring Wells</u>

The recommended method in selection of monitoring well locations has resulted from monitoring at landfills. The strategy is to install one well upgradient from the landfill, with at least three wells downgradient at an angle perpendicular to ground-water flow. This method works well not only for landfills, but for most point sources of pollution.

For situations where the objective is to define the contaminant plume, wells should be installed one at a time, with subsequent well locations determined after sampling of each installed well. A series of monitoring wells should never be installed all at once, based on the initial projection of the extent and flow direction of the contaminant plume (Scalf, et al., 1981, p.16).

The use of 2-inch diameter monitoring wells will limit the size of pump, and thus the depth from which water can be pumped. Most portable submersible 2-inch pumps cannot pump from depths greater than 100 feet. Table 6 shows as summary of the performance characteristics of six small diameter submersible pumps, as tested by the U.S. Forest Service.

Occasionally a well location that is highly desirable from ground-water flow criteria presents unusual problems in design and construction due to geologic factors, access factors, or special environmental problems.

Diameter of well

The diameter of the casing for monitoring wells should be slightly larger than the sampling tool (bailer or pump) to be lowered into the well to the desired depth. This is critical if a pump is to be used to obtain water samples. A pump normally requires some space between the pump bowl and the wall of the screen for best efficiency of operation. For low capacity pumps, this is not as critical as for large capacity production pumps. The diameter of the hole into which the casing is placed must be at least sufficiently large for the casing to fit without having to drive the casing with the casing driver on the drill rig. PVC casing cannot withstand the stresses involved in a drill and drive type of drilling operation. In many cases, the drill hole must be at least 2 inches larger than the casing to permit placement of a grout seal around the outside of the casing.

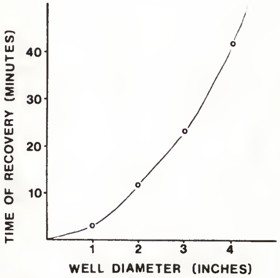
Casings and/or holes drilled much larger than the necessary minimum can, in fact, have undesired effects on the data. For example, in formations of very low permeability the large amount of storage in an unnecessarily large boring can cause the water level inside the boring to be erroneously low for days or even weeks due to the longer time required for recharging the volume of the well. Also, because it is usually necessary to remove water standing in the well before taking a sample of the formation water, large diameter wells require a much greater length of time to purge the well. Another factor is time of recovery after water is removed from the well. Recovery for a small diameter well is substantially faster than for a large diameter well. (See Figure 4.)

Table 6 - Summary of small diameter submersible pumps
(from Karsky, 1982)

| Pump | Head (ft) | Flow Rate (GPM) | Power Source | Cost* | Notes |
|---|---|---|---|---|---|
| Stern Research Pump | 50 | 0.25 | Manual | Approx. $ 100 | Used where more water is to be evacuated than feasible with bail, but not for pumping large quantities of $H_2O$. Not for deep wells--too many sections and too long installation time. |
| Geo filter Model 500 Original | 5<br>20<br>35 | 0.25<br>0.25<br>0.25 | Portable air compressor or compressed gas bottle | Approx. $1,975 plus portable air compressor @ $500 | Original pump |
| Geo filter Modified MEDC w/100 Ft. lg. discharge hose | 5<br>20<br>48<br>78 | 1.20<br>0.94<br>0.75<br>0.50 | Portable air compressor or compressed gas bottle | $1,040 Plus cost to build downhole unit est. @ $600. Plus cost of | Geo filter pump equipment less downhole unit. Replaced w/stainless air cylinder and check valves. |
| Geo Filter (Modified by Geo) | 5<br>20<br>48<br>78 | 0.75<br>0.75<br>0.68<br>0.69 | Portable air compressor or compressed gas bottle | $1,925 ($500 extra for electronic logic unit) | Company modifications larger fluid lines, teflon bladder and larger check valves |
| Bentley Ener-Save Pump<br>SAE 100R Hose<br>SAE 100 R9 Hose | 5<br>5<br>48<br>159 | 1.4<br>2.06<br>1.38<br>0.53 | Gasoline engine | Approx. $3,995 (with 300 ft. of SAE 100R9 Hose) | Hard to prime capable of obtaining samples in deeper wells not stainless steel. |
| Johnson-Keck submersible 125-ft. discharge hose | 5<br>20<br>48<br>78<br>107 | 1.25<br>1.25<br>1.25<br>1.15<br>1.0 | DC power 12v battery, inc. | $3,630 | Simple and easy to use. Very portable. |

*Based on 1982 prices.

TIME REQUIRED FOR WELL RECOVERY WHEN SLUG OF WATER REMOVED




ASSUMPTIONS: $K = 1 \times 10^{-5}$ cm/sec, well screen = 10', 10' of water above screen, 6' of water instantaneously removed

Figure 4. Time required for well recovery (From Rinaldo-Lee, 1983).

The following factors may determine the diameter of a monitoring well:

1. Technical factors:
   a. Recovery time.
   b. Quantity of water available per foot of well (see fig. 15).
   c. Time required to purge well.
   d. Depth to potentiometric surface.
   e. Pump size requirements.

2. Economic factors:
   a. Drilling a small diameter hole may be less costly. However, this is controlled largely by other factors, such as the rock type, and depth of well.

3. Geologic factors:
   a. Drilling may be less costly in alluvial aquifers where a hollow stem auger can be used to drill the well.
   b. Drilling wells in hard formations will often cost at least twice as much as when drilling in softer formations.

In summary, drilling of monitoring wells of 2 inches diameter is not recommended, except for monitoring shallow (less than 50 ft.) aquifers. The use of 4-inch monitoring wells will provide much greater flexibility for future use, and could save money in the long term.

## Depth of Monitoring Zone

The intake port of a monitoring well should be depth-discrete. That is, the screen or other openings, through which water enters the well or casing should be limited to a specific depth range.

Water supply wells that may exist in an area to be monitored are often used as sampling points. Substantial care must be exercised when this is done, and the results are often questionable. Water-supply wells are constructed to produce a given quantity of water, hence, they may be screened throughout a thick aquifer, through several permeable layers of an aquifer, or sometimes through two or more aquifers or discrete water-bearing layers. When this situation exists, it is possible that the hydrostatic heads are different between different layers. Under non-pumping conditions this interconnection permits water from the layer with the higher head to flow upward through the well and into the formation with the lower head. This can occur between layers of different permeability separated by only a few feet of low permeability material. This situation can have substantial effect on the concentration of a pollutant obtained by pumping for a only short time before sampling.

It is important that monitoring wells be constructed to be depth-discrete and to sample only from one specific layer without interconnection to other layers. In order to assure that this depth-discrete requirement is met, provisions for placing cement grout above and, if necessary, below the well screen on the outside of the casing must be made in the design of the wells. However, this technique is very expensive to use, and is justified only in special situations.

Commonly (especially when sampling for contaminants which are less dense than water) it is desirable to sample at the water table, or at the top of the saturated zone in an unconfined aquifer. The screen or intake part of the well should then extend from a few feet above, to a few feet below the anticipated position of the water table to allow for future water-table fluctuations. Often, under semi-confined aquifer conditions, the water will rise in the well above the top of the more permeable layer and above the top of an improperly positioned screen. Care must be exercised in these cases to extend the screen high enough to be above the water level in the formation; otherwise, light organics or other contaminants could be undetected or at least not properly quantified during monitoring.

On the other hand, a contaminant can migrate along fairly restricted pathways and go undetected by depth discrete wells that are not completed at the proper depth. This danger is particularly present in a geologic environment of highly stratified formations, and in fractured rock formations (Scalf, et al., 1981, p. 18).

## Monitoring Well Design

That part of the well through which water enters the casing must be properly constructed and developed to avoid subsequent sampling problems. Commercially made well screens used in water-supply wells are recommended for most monitoring wells even though well efficiency is not a primary concern. Other choices are sawed or torchcut slots in the well casing. Torch-cut slots are not recommended except perhaps for wells drilled in bedrock aquifers where infiltration of fine particles will not be a problem.

Design criteria for the intake part of the well (Scalf, et al. 1981, p.18-19) are:

1. The screen or intake port should have sufficient open area to permit the easy inflow of water from the formation.
2. The slot openings should be just small enough to keep most of the natural formation out, but as large as possible to allow easy flow of water.
3. The well should be properly developed (e.g. over-pumping, surging, backwashing).

Geothermal Systems Monitoring

Monitoring the impacts from geothermal energy development, conversion, and waste disposal is similar to ground-water monitoring for other purposes, except that additional detail is required about the geothermal reservoir. The reservoir needs to be defined in as much detail as possible. For example, the relationship between the geothermal and non-geothermal fluids needs to be established. Information is needed on: (1) The depth and extent of the geothermal reservoir, (2) fluid temperature, (3) pressure, (4) chemistry of fluids, (5) type of geothermal system (vapor-dominated or fluid-dominated), (6) lithology and mineralogy of the reservoir rock, (7) the location of recharge areas, and (8) the mechanism of recharge to the geothermal system. (Hess, et al., 1984)

## Computer Modeling

Models are cartoons of reality. Ground-water models, whether physical or numerical, are only a limited representation of an actual system. The kinds and complexities of numerical models vary according to the specific problem. For example, a study of the effects of varying pumping rates may only require a simple, saturated ground-water flow model. Complex environmental problems, however, may require models of both partially saturated and saturated hydrologic flow as well as contaminant models.

For an excellent discussion of ground-water modeling, see Mercer and Faust (1981). For an in-depth rigorous treatise on modeling, see Wang and Anderson (1982). For information on all the various kinds of models available, and information on how models can be used, see Van der Heijde et al. (1985), and Bachmat, et al., (1980). The reference by Van der Heijde (1985) contains summaries of 399 models used in ground-water evaluations. This report is an update of the report by Bachmat et al. (1980), which contained summaries of 250 models.

Hydrologic and transport models attempt to duplicate the real system by a series of equations that describe fluid flow and material transport. The advent of high speed digital computers has made the solution of these complex sets of equations practicable and cost effective for the following:

* Predicting system response to various proposed management alternatives

* Testing the adequacy of various engineering designs

* Providing insight on the system and making predictions of system response to various perturbations

* Determining sensitivity of the system to variations in actual data.

## Steps Involved in Modeling

* Discovery of a problem and definition of study objectives

* Gathering of existing data relevant to the problem or objectives

* Formulation of a conceptual model of the hydrologic system and identification of data gaps

* Selection of an appropriate model (physical, mathematical, or numerical) and translation of the conceptual model and data on the system into the format required for the selected model

* Calibration (and validation) of the model

* Identification of the significant or dominant parameters that control the process being modeled through parameter sensitivity studies

* Identification of uncertainty in model predictions through sensitivity studies

* Using model as a predictive or investigative tool to attain the study objectives

* Continued use and update of the model as more data and understanding of the system is developed during implementation of remediation and additional monitoring and site characterization activities

## Landfill Leachate Model

The Environmental Protection Agency contracted in 1982 with the U.S. Army Corps of Engineers Waterways Experiment Station (WES) to develop a reliable model to use in evaluating leachate migration from landfill sites (Schroeder et al., 1984).. The model, known as the Hydrologic Evaluation of Landfill Performance (HELP) model is available to BLM through the State Office hydrologist in Idaho. In addition, this model has been reprogrammed for the IBM PC, and will soon be available through the Ground-Water Coordinator at DSC, and the Idaho State Office hydrologist.

The Hydrologic Evaluation of Landfill Performance (HELP) computer program is a quasi-two-dimensional hydrologic model of water movement across, into, through, and out of landfills. The model accepts climatologic, soil, and design data and utilizes a solution technique that accounts for the effects of surface storage, runoff, infiltration, percolation, evapotranspiration, soil moisture storage, and lateral drainage. Landfill systems including various combinations of vegetation, cover soils, waste cells, special drainage layers, and relatively impermeable barrier soils, as well as synthetic membrane covers and liners, may be modeled. The program was developed to facilitate rapid

estimation of the amounts of runoff, drainage, and leachate that may be expected to result from the operation of a wide variety of landfill designs. The model, applicable to open, partially closed, and fully closed sites, is a tool for both designers and permit writers.

The HELP model is applicable to most landfill applications, but was developed specifically to perform hazardous waste disposal landfill evaluations as required by the Resource Conservation and Recovery Act. Hazardous waste disposal landfills generally should have a liner to prevent migration of waste out of the landfill, a final cover to minimize the production of leachate following closure, careful controls of runon and runoff, and limits on the buildup of leachate head over the liner to no more than one foot. The HELP model is useful for predicting the amounts of runoff, drainage, and leachate expected for reasonable design as well as the buildup of leachate above the liner. However, the model should not be expected to produce credible results from input unrepresentative of landfills.

Aquifer parameters for modeling

Historically, ground-water studies have been concerned with water supply. As a result, the data base on aquifer parameters that has accumulated contains mostly information on highly permeable media. For low permeability media, such as many igneous and metamorphic rocks, and for salt formations that have obvious water quality problems, information on physical parameters is much less developed.

Information on aquifer parameters for various rock types is available from a recent study by the Nuclear Regulatory Commission (NRC). The NRC made a study of ground-water parameters and variables that could be used when modeling contaminant transport for nuclear repository sites (Mercer, et al., 1982). However, this information is also applicable to many ground-water models that are not specifically designed for repositories. The information can be used in simple analytical models, or in more sophisticated numerical models. This reference should be consulted if numerical values are needed for such things as permeability, dispersion coefficient, storage coefficient, infiltration, recharge, etc. This reference is an excellent source of data for ranges of values of almost any variable appearing in ground-water models.

## HYDROGEOLOGIC SYSTEM ANALYSIS FOR LEVEL II

### Methodology

The objective of a Level II evaluation is to refine the conceptual model of the ground-water system which was developed in the Level I evaluation. This is done by analyzing data pertaining to the hydrogeologic system.

This involves quantitatively describing the hydrogeologic properties of aquifers and aquitards, and the response of aquifers to development and management practices. The aquifer boundaries must also be described, as

to whether they are no-flow, constant head, or leaky boundary situations. In dealing with problems related to use of ground water, the hydrogeologist must relate draft to water-level change with respect to time and space.

Definition of hydrogeologic characteristics for Level II will be as comprehensive as possible. The result should be a detailed description of the aquifer system and its geologic and hydrologic characteristics. For example, in studies related to spoil piles and coal strip mining, this will include (1) definition of ground-water usage, (2) identification of potential pollutants, (3) definition of hydrogeologic situation, (4) study of existing ground-water quality, (5) evaluation of mobility of pollutants in the vadose zone, (6) evaluation of mobility of pollutants in saturated zone, and (7) assessment the applicant's proposed monitoring plan, or development a monitoring plan if required. A good understanding of the hydrogeologic characteristics of the system will help answer these related questions. Thus, understanding the hydrogeologic situation is prerequisite to all other studies.

Presentations of data useful at Level II are: (1) ground-water contour maps, (2) water level change maps, (3) ground-water inflow-outflow tabulations, (4) direction-of-flow maps, (5) isosalinity maps in areas containing saline water, (6) water quality maps, and (7) saturated-thickness maps.

Techniques for developing a water level contour map are described by Heath and Trainer (1981). A good description of water-level-change maps is given in United Nations (1977, p. 143). For isosalinity maps, see Kelly (1974).

Precisely defining a hydrogeologic system may be difficult, owing to sparsity of data, economic and manpower limitations, and time constraints. Therefore, the probabilistic approach to ground-water studies is usually chosen over the deterministic approach. For example, analytical models can provide reliable solutions, but will lack the exact precision that a complex numerical model can provide. Data are most often not available for the specific hydrogeologic situation being evaluated, and the cost involved in obtaining this information does not justify using the deterministic approach.

Knowledge of the hydrogeologic framework is important from two standpoints: (1) prediction of ground-water movement, and (2) geochemical considerations that affect the quality of ground water. The geologic framework includes lithology, texture, structure, mineralogy, and the distribution of the materials through which ground-water flows. The hydraulic properties of the earth materials depend upon their origin and lithology, as well as the subsequent stresses to which the materials have been subjected. Ground-water movement depends upon the effective permeability and the hydraulic gradient within an aquifer. Permeability is related to the nature, size, and degree of interconnection of pores, fissures, joints, and other openings (Scalf, et al., 1981, p.5-6).

Skimpy data do not preclude a quantitative evaluation of cause-and-effect relations. Approximate solutions, based on existing data and properly qualified, can be important. For example, simple analytical models using estimated values for transmissivity or other aquifer properties can be used to predict drawdowns and yields.

## Developing a Conceptual Model

As interpretations become more complex, ground-water modeling is often used to make predictions about the ground-water system. Hydrogeologic systems analysis involves understanding the various interrelationships of the ground-water system; this can be on a local scale, or a large basin-wide scale. The complexities are often the same, only the scale is changed.

Geology is of primary importance in developing the conceptual model. Ground-water occurrence is dependent on variations in lithology and structure. Although hydrogeology can often be reduced to these two factors, understanding the exact configuration and the interrelationships of these can be very complex and require substantial expenditures of time and money.

Understanding ground-water systems involves creating a three-dimensional conceptual model of the site. As hydrogeologic data are gathered, draw vertical cross-sectional diagrams for visualizing subsurface conditions and identifying data deficiencies. Delineate geologic formations, aquifers, structures, and water tables or confined aquifer pressure surfaces.

Available data should be used to develop a model of the ground-water system. Data used should encompass all factors bearing on the area's hydrology--surface water, ground-water levels, precipitation, vegetation, topography, and so forth. For example, the occurrence and distribution of numerous springs can indicate much about ground-water conditions. Similarly, vegetation provides clues to the ground-water system and subsurface geology. For a good discussion of phreatophytes relative to ground water, see Robinson (1958).

## Conducting Field Investigations

Prior to initiating any field work, all existing geologic and hydrologic data should be collected, compiled, and interpreted. Data that may be available include: geologic maps, cross-sections, aerial photographs, and an array of water-well data including location, date drilled, depth, name of driller, water level and date, well completion methods, use of well, electric or radioactivity logs, or other geophysical data, formation samples, pumping test(s), and water-quality data. After compiling and thoroughly reviewing the collected data, the investigator can properly plan the type of investigation needed, including the data necessary to fill the gaps and the required sampling (parameters, frequency, and locations).

Report Criteria

The following reporting techniques should be used when conducting ground-water system analyses:

1. Develop a Conceptual Model of the Ground-Water System. This is done through the following process:

a. Plot all available water well information (see Level I parameters plus Level II collection) on a base map (may be Level I base map if space permits). This may include information from unpublished sources and extrapolations developed to fill data gaps. Much can be revealed about the ground-water system if data are abundant and fully plotted.

b. Indicate the range in well depths and depth to water in each unit.

c. Discuss briefly, for confined aquifers, the producing zone (depth), the amount of head in the system, and the formation (name) where the water originates.

d. Delineate aquifer boundaries and geologic outcrops by using surficial geologic information to show unconfined or water table conditions and subsurface geology correlated to outcrops of bedrock. Where ground water is at or near the surface, indicate its significance. For example, an area perennially wet may indicate not discharge from an unconfined or confined system but merely a local perched water table.

e. Plot directions of ground-water movement for the study area on the aquifer map if space permits. This will depend on the density of wells.

2. Consider water-quality data. The Intensive Level of Interpretation may require the actual plotting of raw water-quality data into Trilinear, Stiff, or Piper diagrams to fill gaps or confirm anomalies. Interpreting water-quality data can involve considerable extrapolation or interpolation. Time variability in water composition is usually less important than areal variations.

Standard methods for analysis of most organic and inorganic components of ground water are well advanced, including determinations of common mineral constituents, dissolved gases, radionuclides, pesticides, and trace metals. Methods of interpretation and presentation of data are described in Hem (1970), Heath and Trainer (1981), and Davis and DeWeist (1966).

a. Delineate areal variations in water quality, aquifer by aquifer, relating the chemical distribution to ground-water flow patterns and rock composition. This relationship is examined in detail by Hem (1970). Evaluate native plants as an indicator of ground-water quantity and quality. For a good discussion of phreatophytes relative to ground water, see Robinson (1958).

b. Prepare, where data suffice, maps indicating time related conditions (historical, current, or projected), or general quality assessments (electrical conductivity or total dissolved solids), or particular facets of quality (nitrate concentration, temperature).

c. List and discuss the water-quality data obtained from the literature, records, and field observations. Relate current withdrawals to uses and discuss measures required for maintenance of water quality.

3. Quantitatively evaluate data on those stresses affecting the ground-water flow system. Examples include mine dewatering, withdrawal, or waste disposal injection.

The response of a ground-water system depends on the aquifer parameters (transmissivity and storage coefficient), the boundary conditions, and the positioning of the development within the system. In dealing with problems related to use of ground-water resources, the hydrogeologist must relate draft to water level change with respect to time and space. In ground-water systems the decline of water levels in a basin because of withdrawal will occur over a period of years, decades, or even centuries. Some water must be taken from storage in the system to create gradients toward a well. There are two implications to be gathered from these facts: (1) some water must always be mined (pumped) to create a development, and (2) the response times in a ground-water system differ markedly from those in surface water systems (Nat. Acad. Sci., 1982, p. 52). The lack of basic data does not dictate that quantitative evaluations of cause-and-effect relations cannot be made. Approximate solutions, based on existing data and properly qualified, can be of great importance. For example, the use of simple analytical models using estimated values for transmissivity or other aquifer properties can be used to predict drawdowns, yields, etc.

4. Analyze the potential development capability of the ground-water resource. Utilize transmissivity data or specific capacity data and analyze water level changes over time (where available). Pay attention to the time span in which water level fluctuations occur. Recurrent fluctuations of several feet over a short period would be significant and be cause for further investigation. In most ground-water systems, replenishment and discharge of the aquifer is nonuniform in time and space; the hydrogeology is irregular and pumping stresses are rarely uniformly distributed. Solving ground-water problems usually depends on both scientific principles and/or professional judgment.

5. Present data on a map of the area. Presentations of data useful at this level are: (1) ground-water contour maps, (2) water level change maps, (3) ground-water inflow-outflow maps, (4) flow direction maps, (5) isosaline maps (in areas of aquifers containing saline water), (6) water-quality maps, and (7) saturated thickness maps.

6. Model the ground-water system. Modeling ground-water flow systems is no longer the domain of large mainframe computers. Microcomputers are fully capable of modeling ground-water flow systems. There are limitations on the size of the model (i.e., the number of nodes, or calculation points) used on a microcomputer; however, most situations can be handled on any desktop micro having at least 256k of random access memory (RAM). Preferably, the micro should have 512k of RAM memory, which will provide faster execution times of most routines. Floating-point math cards or special math co-processor cards may need to be installed for certain kinds of calculation-intensive models.

There are several finite difference models available for microcomputers. Perhaps the most widely used model in the ground-water profession currently is the Prickett-Lonnquist model. This model simulates two-dimensional flow, and has been modified into several versions to handle a wide variety of unconfined and confined flow situations. As an example of the flexibility of this model, it is available for the Apple IIc microcomputer having only 64k RAM. The model is limited to a grid size of 20 x 20 nodes, which is usually adequate for general approximations. Model run-time is about 10 minutes per data set.

There are also several analytical models available for microcomputers that will solve most of the ground-water problems encountered in BLM. These models provide a cost-effective means of evaluating ground-water systems. The ground-water coordinator at DSC can provide assistance in locating the appropriate model for a particular need (see Appendix J).

Even though microcomputers are available to run models, numerical modeling is still a time-consuming process, and should not be used unless absolutely necessary. Analytical modeling should be used in preference to numerical modeling. The analytical models provide quick and relatively easy "back of the envelope" type solutions to most ground-water flow problems.

## WATER QUALITY SYSTEM ANALYSIS FOR LEVEL II

### Investigative Procedure

A Level II investigation goes beyond characterization of water quality of the aquifers. This more comprehensive approach is the system analysis, in which the interrelated water quality components are evaluated in systematic way.

The following procedure is recommended for conducting hydrogeologic investigations that focus on water-quality considerations:

#### Delineate monitoring area

The monitoring area will be determined by administrative, physiographic, and risk assessment factors. Administrative considerations include coordination with monitoring programs of other agencies. Also, administrative boundaries may cross a ground-water basin, complicating the coordination role between regulatory entities. Physiographic considerations recognize that ground-water basins often coincide with watershed drainage basins. By selecting a monitoring area within a single watershed, total hydrologic inflows and outflows may be accounted for; the resulting hydrologic analysis is much easier to accomplish.

Risk assessment factors include consideration of localities which have a large number of identified or potential pollution sources, and locations of nearby uses of ground water for human consumption. For a disscussion of risk assessment in general, see Appendix K

#### Identify pollution sources

Ground-water pollution sources can be grouped into six major categories. Municipal, agricultural, and industrial sources are obvious major groups; mining and oil field wastes are of sufficient importance to be considered major sources of contamination. The sixth group is a miscellaneous category which includes septic tanks and cesspools, highway deicing salts, and spills or accidents.

#### Identify Potential Pollutants

Pollutants are classified as physical, inorganic chemical, organic chemical, bacteriological, and radiological. Major groups of potential pollutants and some of the more prevalent constituents for each group are shown in the following classification:

**Physical**

- Temperature
- Density
- Odor
- Turbidity

**Organic Chemical**

- Carbon
- Chlorophylls
- Extractable Organic Matter
- Methylene Blue Active Substances
- Nitrogen
- Chemical Oxygen Demand
- Phenolic Material
- Pesticides, herbicides, and insecticides

**Bacteriological**

- Coliform Group
- Pathogenic microorganisms
- Enteric viruses

**Inorganic Chemical**

- Major Constituents
- Other Constituents
- Trace Elements
- Gases

**Radiological**

- Gross Alpha Activity
- Gross Beta Activity
- Strontium
- Radium
- Tritium

Define Ground-Water Usage

The quantities of water being extracted from an aquifer and the locations of major pumping centers need to be identified. Pumpage near pollution sources can disrupt normal ground-water flow paths, changing the direction of flow, resulting in unexpected contamination of drinking water supplies. Ground-water monitoring systems need to be carefully designed to take into account all possible influences on the flow system.

Define Hydrogeologic Situation

To understand where and how ground-water pollution occurs and moves within a monitoring area, the hydrogeologic framework must be understood. This information will aid in the evaluation of pollutant movement as well as in the design of efficient ground-water quality monitoring systems.

Because some subsurface data are available in most areas of ground-water development, initial hydrogeologic work will consist of gathering, organizing, and analyzing existing information. In some cases, geologic or hydrologic investigations requiring field work will be necessary. Specific materials needed for the evaluation, as well as how they are obtained, include the following:

1. Aquifer locations, depth, and areal extents - from geologic data.
2. Transmissivities of aquifers - from well pumping tests and geologic data.
3. Map of depths to ground water - from water levels and topographic data.
4. Areas and magnitudes of natural ground-water recharge - from precipitation, evapotranspiration, soils, land use, and water level data.
5. Areas and magnitudes of natural ground-water discharge - from spring locations, wetlands, streamflow, and water level data from wells..
6. Directions and velocities of ground-water flows - from water level and transmissivity data.

In preparing the above materials, it should be kept in mind that these pieces of information serve as tools for the evaluation. Consequently, the collection of hydrogeologic data should not become an obstacle to the completion of the overall analysis. All hydrogeologic data are incomplete in a relative sense. What is needed is an overall picture of the hydrogeologic situation in the monitoring area. Initially, refinement is less important than comprehensive coverage, no matter how preliminary or approximate. Categories indicating ranges rather than specific values, such as for transmissivity or dissolved solids, are often sufficient. Also, it should be recognized that, with time and with increasing amounts of ground-water and geologic data, knowledge of the hydrogeologic situation will gradually improve, and refinements can be

made to the concept of how the system operates (Everett, 1979, p.78).

## Study Existing Ground-Water Quality

In order to define the ground-water quality problems within a monitoring area, an assessment needs to be made of the background water quality situation. To do this, recent ground-water quality data need to be collected and reviewed. Attention should be focused first on the natural ground-water quality. A map of indicators of pollution in ground water, taking into account areal variations as well as variations with depth, could be prepared from available well-water analyses. This map will typically show a limited range of values where pollution is not present within an aquifer. However, if considerable variability or isolated anomalies are evident, these may be indicative of the presence of pollution.

It is often surprising how much water quality data, after investigation, are actually available. Judgment, however, must frequently be exercised so as to select meaningful data and to avoid those which are erroneous. A certain amount of ingenuity is required to locate fragmented data and to interpret them in terms of the subsurface situation.

In addition to collecting current data, past ground-water quality records should be reviewed whenever possible. Historical water quality records are helpful in establishing the quality of native ground water, in evaluating quality trends with time, and in relating changes in ground-water quality to sources and causes.

Information sources for ground-water quality data should normally include State geologic and water agencies, the USGS, EPA's STORET data base, local water and regulatory agencies, universities, and consulting firms or individual consultants.

## Evaluate Infiltration Potential of contaminants at the Land Surface

Major sources of pollution at the land surface are surface impoundments, mining waste (spoil piles and tailings), open dumps, landfills, and pesticides or herbicides. The volume of polluted water passing through the vadose zone into the saturated zone needs to be determined. This volume will depend on the method of waste disposal used and the infiltration characteristics of the soil or the other surficial geologic units.

Contamination of ground water at a particular surface impoundment will depend on (1) soil permeability, (2) depth to the water table, (3) rates of evaporation and precipitation (including potential for overflow), (4) geochemical characteristics of the soils, (e.g., ion exchange and absorption), (5) chemical composition and volume of the waste, and geology of the site. (Office of Tech. Assessment, 1984 p. 275)

EPA analyzed 416 case studies of ground-water contamination from surface impoundments, and found that in 78.7 percent of the cases, contamination was the result of direct seepage; 10.1 percent by dike failure or overflow; 7.6 percent by liner failure; 1.6 percent by catastrophic collapse, and 2.0 percent by other causes. (Office of Technology Assessment, 1984, p. 275).

Evaluate Mobility of Pollutants from Land Surface to Water Table

Pollution attenuation in the subsurface commonly occurs due to the following processes: dilution, filtration, sorption, buffering, precipitation, oxidation-reduction, volitization, biological degradation and assimilation, and radioactive decay. Each of these processes should be evaluated with respect to specific pollutants.

Evaluate Attenuation of Pollutants in the Saturated Zone

Dilution and related factors: Once percolating wastes reach the zone of saturation in most ground-water systems, there will be attenuation of pollutant concentrations with distance. This type of attenuation is one of the primary factors that mitigates against widespread ground-water pollution. In one sense, attenuation is analogous to the dissipation of a plume of smoke. The attenuation occurring in most cases is determined by the following factors:

1. The volume of waste water reaching the water table.
2. The waste loading, i.e., the weight per unit area of pollutant reaching the water table.
3. Areal hydraulic head distribution, as indicated by water-level evaluation contour maps.
4. Transmissivity of aquifer materials.
5. Vertical hydraulic head gradients and vertical permeabilities through confining beds which are present.
6. Quality of native ground water in a three-dimensional sense.
7. Quantity of recharge reaching the water table from other sources at the land surface.
8. Quality of recharge reaching the water table from other sources.
9. Well construction.
10. Pumpage volumes and patterns.

The first two factors determine the concentration of pollutants reaching the water table. The third and fourth factors, along with porosity, determine the direction and magnitude of horizontal ground-water inflow and outflow from the area. The fifth factor determines the direction and magnitude of vertical ground-water flow in the area. The sixth factor comprises the quality of ground water with which the recharged wastewater will mix. The seventh and eighth factors determine the effect of recharge from other sources on pollutant concentration. Lastly, well construction can allow short circuiting of aquifer materials and well pumping can drastically alter the hydraulic head distribution, and thus the direction of ground-water flow.

Processes other than dilution: The attenuation processes other than dilution do not generally have to be considered in detail if there is an adequate thickness of the vadose zone for treatment. In cases where the water table is shallow or a large part of the vadose zone is bypassed during waste disposal, detailed consideration of saturated flow conditions for filtration and sorption, buffering, chemical precipitation, and oxidation and reduction processes may be necessary.

### Evaluate Existing Monitoring Programs

Every effort should be made to incorporate any existing monitoring programs being conducted either in the study area or nearby, to provide a comprehensive and cost-effective monitoring network.

### Establish Alternative Monitoring Approaches

Because it is possible to have several monitoring zones, sample analyses, and sample frequencies to meet the same technical objective, more than one monitoring approach may exist for an objective. After initial monitoring of a site, it may be determined that a pollutant-specific monitoring method is required. More frequent sampling or special handling of samples may be required for certain situations. Ground-water monitoring is never a static operation. The monitoring data must be evaluated early in the monitoring program to detect inconsistencies in the data which might require changing the monitoring method, or the lab procedure.

### Select and Implement Monitoring Program and Mitigation Measures

Utilize graphical methods whenever possible to detect trends and to design changes in the monitoring strategy. Statistical analysis of the data may be required; several software packages are now available for microcomputers to accomplish this. For information on graphical methods of depicting water quality data, see the graphical methods section of this report.

## Data Interpretation

Interpreting water-quality data can involve considerable extrapolation or interpolation. Temporal variations in water composition are usually less important than areal variations, and generally the investigator must extrapolate from individual wells or springs to cover a broad area, delineating areal variations in water quality, aquifer by aquifer, relating the chemical distribution to ground-water flow patterns and to rock composition.

Standard methods for analysis of most organic and inorganic components of ground water are well advanced, including determinations of common

mineral constituents, dissolved gases, radionuclides, pesticides, and trace metals. Methods of interpretation and presentation of data are described in Hem (1970, 1985), Heath and Trainer (1981), and Davis and DeWeist (1966).

List and discuss the water-quality data obtained from the literature, well records, and field observations. Relate current withdrawals to uses, and discuss measures required for maintenance of water quality. Evaluate native plants as an indicator of ground-water quantity and quality.

Identify areas on the base map where vulnerable aquifers exist, or where potential or active sources of contamination exist. The EPA has developed a ground-water classification system based on beneficial use criterion. These three classifications are: class I, special ground waters; class II, current and potential sources of drinking water; and class III, ground-water which is not a potential source of drinking water and having limited benificial use. Vulnerable aquifers are those that are highly vulnerable to contamination because of their hydrogeologic characteristics (i.e., sand and gravel aquifers or fracture system aquifers (U.S. EPA, 1984, p. 43). Indicate sources of contaminants and relate these to recharge areas, general ground-water flow directions, and discharge points. Flow directions of contaminants relative to known points of use are critical to the investigation strategy.

Determine the basis for particular water-quality problems. For example, natural chemical interactions with rock units rather than man induced pollutants may be responsible for the water-quality problem. Heath (1983) discusses these water-rock interactions in detail (see Tables 7 and 8). Hem (1985) provides perhaps the best available treatise on the subject.

Where data suffice, prepare maps relating quality of ground water to time-related (historical, current, or projected) conditions; or general assessment of quality, such as electrical conductivity, total dissolved solids, or a specific display showing one facet of quality, such as nitrate, temperature, or TDS.

Geohydrochemical maps may need to be prepared. The maps may reveal distinct regional or local differences in chemical composition of ground water. Detailed hydrogeochemical factors can then be evaluated (United Nations, (1977).

The interpretation method used must fit the study or situation at hand. Studies of ground-water systems related to mineral development will require special design, due to the wide range of possible issues that require applied hydrogeologic techniques.

Table 7. Characteristics of water that affect water quality

| Characteristic | Principal cause | Significance | Remarks |
| --- | --- | --- | --- |
| Hardness---------------------------- | Calcium and magnesium dissolved in the water. | Calcium and magnesium combine with soap to form an insoluble precipitate (curd) and thus hamper the formation of a lather. Hardness also affects the suitability of water for use in the textile and paper industries and certain others and in steam boilers and water heaters. | USGS classification of hardness (mg/L as $CaCO_3$):<br>0-60: Soft<br>61-120: Moderately hard<br>121-180: Hard<br>More than 180: Very hard |
| pH (or hydrogen-ion activity)-------- | Disassociation of water molecules and of acids and bases dissolved in water. | The pH of water is a measure of its reactive characteristics. Low values of pH, particularly below pH 4, indicate a corrosive water that will tend to dissolve metals and other substances that it contacts. High values of pH, particularly above pH 8.5, indicate an alkaline water, that on heating, will tend to form scale. The pH significantly affects the treatment and use of water. | pH values: less than 7, water is acidic; value of 7, water is neutral; more than 7, water is basic. |
| Specific electrical conductance------ | Substances that form ions when dissolved in water. | Most substances dissolved in water dissociate into ions that can conduct an electrical current. Consequently, specific electrical conductance is a valuable indicator of the amount of material dissolved in water. The larger the conductance, the more mineralized the water. | Conductance values indicate the electrical conductivity, in micromhos, of 1 $cm^3$ of water at a temperature of 25°C. |
| Total dissolved solids-------------- | Mineral substances dissolved in water. | Total dissolved solids is a measure of the total amount of minerals dissolved in water and is, therefore, a very useful parameter in the evaluation of water quality. Water containing less than 500 mg/L is preferred for domestic use and for many industrial processes. | USGS classification of water based on dissolved solids (mg/L): Less than 1,000: Fresh.<br>1,000-3,000: Slightly saline<br>3,000-10,000: Moderately saline.<br>10,000-35,000: Very saline<br>More than 35,000: Briny |

Source: Heath, R. C., 1983, Basic Ground-Water Hydrology: U.S. Geological Survey Water-Supply Paper 2220, p. 65.

Table 8. Natural inorganic constituents commonly dissolved in water that are most likely to affect use of the water

| Substance | Major natural sources | Effect on water use | Concentration of significance (mg/L)[1] |
|---|---|---|---|
| Bicarbonate ($HCO_3$) and carbonate ($CO_3$)---- | Products of the solution of carbonate rocks, mainly limestone ($CaCO_3$), and dolomite ($CaMgCO_3$), by water containing carbon dioxide. | Control the capacity of water to neutralize strong acids. Bicarbonates of calcium and magnesium decompose in steam boilers and water heaters to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium, cause carbonate hardness. | 150-200 |
| Calcium (Ca) and magnesium (Mg)-------------- | Soils and rocks containing limestone, dolomite, and gypsum ($CaSO_4$). Small amounts from igneous and metamorphic rocks. | Principal cause of hardness and of boiler scale and deposits in hot-water heaters. | 25-50 |
| Chloride (Cl)-------------------------------- | In inland areas, primarily from seawater trapped in sediments at time of deposition; in coastal areas, from seawater in contact with freshwater in productive aquifers. | In large amounts, increases corrosiveness of water and, in combination with sodium, gives water a salty taste. | 250 |
| Fluoride (F)--------------------------------- | Both sedimentary and igneous rocks. Not widespread in occurrence. | In certain concentrations, reduces tooth decay; at higher concentrations, causes mottling of tooth enamel. | 0.7-1.2[2] |
| Iron (Fe) and manganese (Mn)----------------- | Iron present in most soils and rocks; manganese less widely distributed. | Stain laundry and are objectionable in food processing, dyeing, bleaching, ice manufacturing, brewing, and certain other industrial processes. | Fe 0.3,<br>Mn 0.05 |
| Sodium (Na)---------------------------------- | Same as for chloride. In some sedimentary rocks , a few hundred milligrams per liter may occur in freshwater as a result of exchange of dissolved calcium and magnesium for sodium in the aquifer materials. | See chloride. In large concentrations, may affect persons with cardiac difficulties, hypertension, and certain other medical conditions. Depending on the concentrations of calcium and magnesium also present in the water, sodium may be detrimental to certain irrigated crops. | 69 (irrigation)<br>20-170(health)[3] |
| Sulfate ($SO_4$)---------------------------- | Gypsum, pyrite (FeS), and other rocks containing sulfur (S) compounds. | In certain concentrations, gives water a bitter taste and, at higher concentrations, has a laxative effect. In combination with calcium, forms a hard calcium carbonate scale in steam boilers. | 300-400 (taste)<br>600-1,000 (laxative) |

[1] A range in concentration is intended to indicate the general level at which the effect on water use might become significant.
[2] Optimum range determined by the U.S. Public Health Service, depending on water intake.
[3] Lower concentration applies to drinking water for persons on a strict diet; higher concentration is for those on a moderate diet.

Issues related to mining could be (a) leaching of water through spoil piles downward into the ground-water systems, (b) migration into ground-water of toxic materials associated with mining that have been disposed of on the surface, (c) water-rock interaction, as when pH is changed due to contact with certain minerals or oxidation products, and (d) disrupted aquifers, especially sole-source aquifers as defined in section 1424(e) of the Safe Drinking Water Act.

## GROUND-WATER CONTAMINATION STUDIES

All ground-water investigations are not conducted in the same manner. The level of investigation and the methodology employed to solve the particular situation will vary over a wide range of costs and time. These considerations are discussed at length in the following exerpt from a study by the Office of Technology Assessment.

> Different kinds of programs may require different kinds of information. A detection program for water supplies may be limited to identification and quantification of contaminants in public water supplies, as required under the Safe Drinking Water Act. Monitoring under such a program is relatively straightforward because the measuring points are defined as the existing water supply wells, and the type of information required is water-quality data. There is a need to evaluate the hydrogeologic environment to determine where to collect samples. However, samples taken without information about the hydrogeologic environment and associated flow system provide only a single snapshot of water quality--at the place and at the time the sample is collected; they cannot be used either to predict whether water quality is likely to change or to indicate the location of the source of contamination. Alternatively, a detection program to determine whether a source is in fact contaminating ground water requires information on the hydrogeologic environment near the source--in addition to the collection and analysis of water-quality samples--in order to identify areas that are most likely to show evidence of contamination.
>
> The primary purposes for collecting hydrogeologic data are to (1) determine the rate and direction of ground-water flow, (2) evaluate the types of contaminants likely to be found, and (3) determine whether the contaminants and the ground water are likely to be moving at the same rate and direction.

Information about the hydrogeologic environment is important in understanding whether contaminants will move at the same rate as ground water, or if physical, chemical, and/or biological processes are likely to occur that will cause them to move at different rates. Analysis of the physical, chemical, and biological properties of the hydrogeologic environment, along with information on the properties of contaminants, is needed to evaluate the behavior of contaminants in the subsurface. In addition, some human activities can influence the flow of ground water (e.g., pumping ground water for use can alter the direction of flow, and modifications to the land surface can alter the amount of water infiltrating to the ground-water system).

Information on sources of contamination is useful in predicting the types of contaminants likely to be present, their locations, and their concentrations. When interpreted along with data on ground-water flow and associated contaminant behavior, source data can be used to predict the location, rate, and direction of contaminant movement. Knowledge of the contamination source aids in determining the area to be investigated, the sites for collecting water-quality samples, and the sampling and analysis procedures.

Information on properties of contaminants is important in understanding the rate and direction of contaminant movement, the location of contaminants relative to the water table and less permeable units, the persistence of the contaminants in the subsurface, and the types of techniques that can be used to detect, correct, and prevent contamination.

The properties of contaminants that are most important for their detection in the subsurface relate to solubility. Hydrogeologic investigations of contaminants that are only slightly soluble (immiscible) require more information on the hydrogeologic environment and water quality than may be needed to describe contaminants that move with ground-water flow. Immiscible fluids that are also more dense than ground water (e.g., many industrial solvents) may move in a different direction than ground-water flow. Immiscible fluids that are less dense than water (e.g., many petroleum products) tend to float on top of the water table and may require water sampling in the unsaturated zone.

Although the hydrogeologic information shown in Table 9 is useful for accomplishing investigation objectives for most site conditions, the amount and types of information collected in practice are limited because of the time and costs of obtaining and analyzing data. The information collected varies, depending on site conditions and study objectives. The major site conditions that determine the information to be collected relate to the complexity of the hydrogeologic environment, the climate, the number of potential contamination sources, and knowledge of the behavior of the contaminants. (Office of Technology Assessment, 1984, p. 115-117)

Table 9--Overview of information used to characterize hydrogeologic conditions and contaminant behavior [illegible] in [illegible]

| Information obtained for hydrogeologic investigations | Use of information |
|---|---|
| A. Topographic data | Provide partial information on flow (i.e., rate, directions, and pathways of unsaturated zone and ground-water flow and relationship of ground water to surface water including: relative position of water levels in wells, locations of possible discharge and recharge areas, rates of infiltration and surface runoff, and general direction of ground-water flow). |
| B. Vegetative Data | Provide partial information on flow (i.e., rate and pathways of water movement into and out of the subsurface). Also vegetation type and condition may reflect the quality of ground water and be used to identify areas of contamination. Used to estimate depth to water table and identify possible discharge and recharge areas. |
| C. Climatic data (precipitation; evapotranspiration; site temperature) | Provide partial information on flow (i.e., the quantity, timing, and rate of movement of water and contaminants into the subsurface). Provide basic information to assess rate of reactions and biodegradation of contaminants. |
| D. Geologic data (surficial deposits; subsurface stratigraphy; lithology; structural geology) | Provide partial information on flow (i.e., location and volumes of of potential ground-water supplies, pathways for water and contaminant movement into and out of underlying formations, and direction and rate of ground-water movement) and are used to identify possible recharge and discharge areas. Also, provide partial information on mechanical dispersion (mixing) and attenuation reactions of contaminants. |
| E. Surface hydrology data (overland flow; stream discharge; stage; recurrence interval; baseflow discharge) | Provide partial information on flow (i.e., quantity, rate, and timing of water movement into and out of subsurface). Used to identify and quantify possible discharge and recharge areas, and to identify potential conduits for contamination. Surface water may affect concentrations of contamination at discharge points. |
| F. Unsaturated zone data (water table; geometry; hydraulic properties: effective porosity, effective permeability, relative permeability, permeability, specific storage; flow parameters: pressure head, hyd. gradient, fluid saturation; recharge/discharge) | Provide partial information on flow (i.e., on the flow regime which influences the rate, direction, and quantity of water and contaminants moving from the surface into the saturated zone). Usually relatively unimportant in the humid areas such such as the Eastern United States. |
| G. Saturated Zone data (aquifer characterization: confined aquifers, unconfined aquifers, leaky aquifers; hydraulic parameters of aquifers: storativity, transmissivity, primary porosity, secondary porosity; confining unit geometry; hydraulic parameters of confining units: hydraulic conductivity, specific storage; flow parameters: water levels, hydraulic gradient, flow velocity; recharge/discharge: precip. contributions, confining layer leakage) | Provide partial information on flow (i.e., the rate, direction, and quantity, of ground water and contaminant flow). Also, provide partial information on recharge and discharge characteristics. |
| H. Contaminant transport parameters (distribution coefficient; dispersivity coefficients; flow velocities; relative saturations; cation exchange capacity; subsurface mineralogy; ambient water chemistry; microbiology) | Provide parital information on properties of the hydrogeologic environment that influence the potential for physical, chemical, and biological reactions that result in contaminants moving at different rates than water through the ground-water flow system. |

OTA, p.116

Hydrogeologic information collected will vary under different site conditions. For example, the following variations are commonly encountered, which can require modifications of the investigation strategy:

* In fractured (as opposed to unfractured) aquifers, information is needed on fracture patterns, joint patterns and spacings, and possibly dual porosity properties (i.e., primary and secondary permeability and porosity).
* In semi-arid (as opposed to humid) climates where the water table is deep, information on the properties of the unsaturated zone (e.g., moisture content and relationships between relative permeabilities and capillary pressure) is very important for defining ground-water flow and determining the potential for contamination.
* Where multiple sources (rather than a single source) of contamination are suspected, water-quality sampling and analysis may be directed more to contaminants that are unique to a particular source, perhaps at very low concentrations, than to contaminants that are likely to be found at the highest concentrations.
* Where the behavior of contaminants can be readily described--for example, by having knowledge that the contaminant is quickly degraded or strongly retarded in ground water--collection of data on water quality can be concentrated in areas near the source rather than over a wider area. (Office of Technology Assessment, 1984)

When conducting ground-water contamination studies, there are several types of information that cannot be obtained reliably due to extremely complex technical considerations. These include:

1. Chemical reactions in fluids containing multiple contaminants.
2. Properties characterizing in detail ground-water flow and chemical transport in fractured media.
3. Certain hydraulic properties of very low permeability media.
4. In-situ determinations of hydraulic properties in the unsaturated zone when immiscible contaminants are present.
5. History of the contaminating source. (Office of Technology Assessment, pp. 125-126).

## Sources of Ground-Water Contamination

Ground-water contamination can originate from a wide variety of sources. Many of the sources are the result of activities on Public Land. Each type of source might require a different approach when conducting a hydrogeologic investigation. The following list shows some of the various sources that have been identified by EPA (Office of Technology assessment, 1984b, p.309):

1. Landfills
    a. sanitary
    b. hazardous waste

2. Open dumps

3. Waste piles

4. Surface impoundments

5. Subsurface percolation systems
(e.g., septic tanks, cesspools)

6. Injection wells

7. Disposal of waste treatment by-product
(e.g., sludge)

8. Disposal of waste waters
(e.g., spray irrigation)

9. Agriculture
   a. Irrigation return flow
   b. Pesticides, herbicides
   c. Feedlots
   d. Fertilizers
   e. Runoff

10. Saltwater intrusion brackish water upconing

11. Spills, accidents

12. Leaks from storage, pipelines, etc.

13. Transportation (e.g., airports, loading docks)

14. Drainage from active/abandoned mines

15. Infiltrating stormwater, urban runoff

16. Percolation of atmospheric contaminants

17. Aquifer disruption due to construction/excavation

18. Deicing salts

19. Abandoned wells

20. Other

## GRAPHICAL METHODS OF DEPICTING GROUND-WATER QUALITY DATA

Graphical presentation of ground-water data is extremely important to the success of any ground-water study. The use of graphical techniques will provide ease in understanding the sometimes complex chemical

composition of ground water. Graphical techniques can also be used to make comparisons of two or more ground-water sources, and to evaluate mixing of ground waters. Some graphical methods are useful for placing on the hydrogeologic base map, to show spacial distribution of constituents.

Very little standardization exists in the use of map symbols for depicting ground-water quality. The only internationally accepted standards are found in the International Legend for Hydrogeological Maps and the Legends for Geohydrochemical Maps (United Nations, 1977, p.156).

The most widely used graphical procedure for displaying ion concentrations is the vertical bar system developed by Collins (1923). This method uses a vertical bar whose weight is proportional to the total concentration of anions or cations in milliequivelents per liter. Horizontal lines are used to separate the concentrations of various ions. Usually, six divisions are used, although more can easily be added if required. An example of the Collins method is shown in Figure 5. A variation of this method, showing the addition of hardness data, is also commonly used and is shown in Figure 6.

Another widely used method is the "Stiff diagram," developed by H.A. Stiff in 1951. This method uses four parallel horizontal axes extending from each side of a vertical zero axis. Concentrations of four cations may be plotted, one on each axis to the left of zero, and four anion concentrations are plotted on each axis to the right of zero; the ions must always be plotted in the same sequence. The concentrations are expressed in milliequivalents per liter. The resulting points are connected to give an irregular closed pattern, as displayed in Figure 7. This method gives a distinctive pattern, and is very useful in depicting water composition differences or similarities. The pattern for a particular water source tends to maintain its shape, even upon concentration or dilution of the constituent. Thus, a study of water quality patterns can often be utilized to identify different producing strata, and correlate water sources with strata over an area (Stiff, 1951).

A vector system of map symbols was developed by Rezso Maucha of Hungary whereby the length of six vectors represents the concentrations of one or more ions in milliequivalents per liter. Though seldom used in the United States, this system is useful for plotting analytical values in a small space, such as on a map (see Fig. 8) (Hem, 1970).

A map symbol system developed by Colby, Hembree, and Rainwater (1956) presents four components ($Ca^{+2}$ + $MG^{+2}$, $CO_3$ , $NA^+$ + $K^+$, and Cl + $SO_4$ + $NO_3$) on rectangular coordinates. Connecting the four points makes a convenient kitelike symbol (Fig. 9).

The trilinear diagram is also useful. One of the earliest applications was in analyzing mine-water composition (Hem, 1970, p. 264). Piper's variant on the trilinear diagram effectively segregates

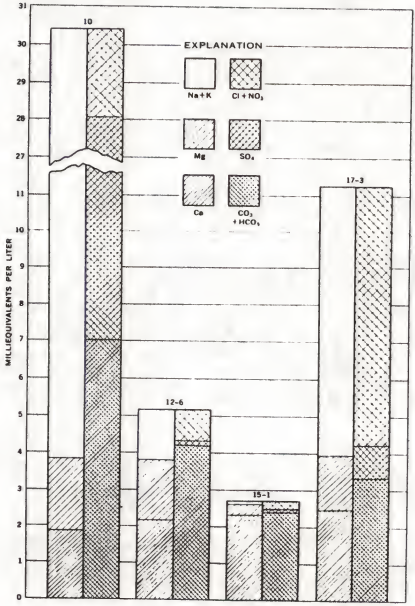



Figure 5. Collins ion-concentration diagram (From Hem, 1970).

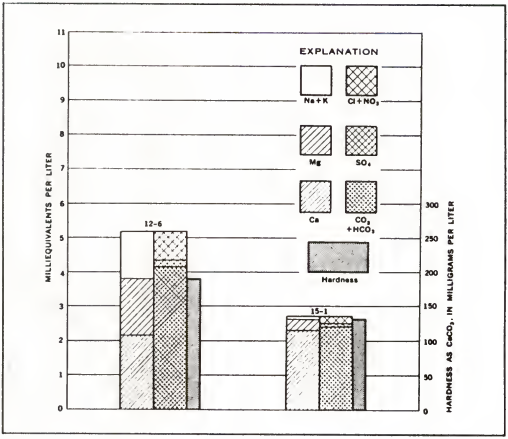



Figure 6. Variation of Collins diagram with hardness component added (From Hem, 1970)

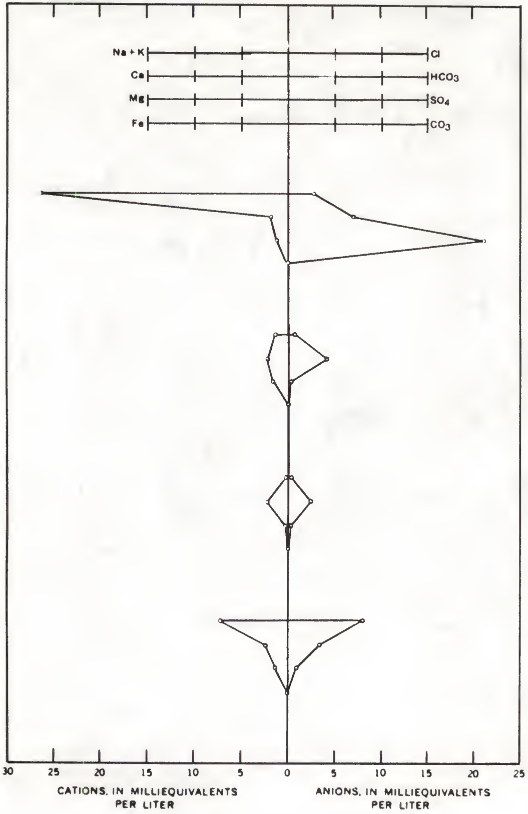



Figure 7. Stiff diagram—each shape is a different water source (From Hem, 1970)

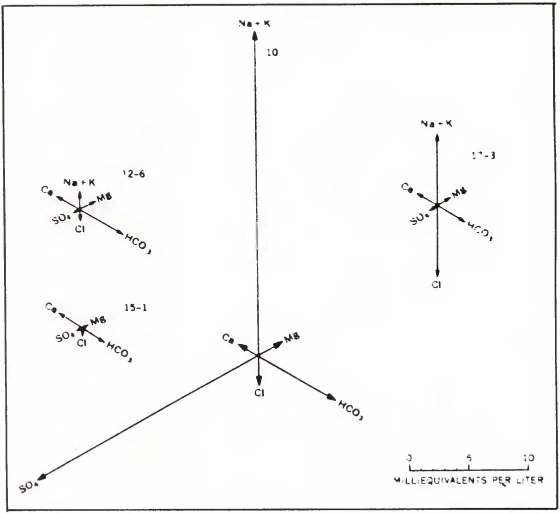



Figure 8. Ion-concentration diagram using radiating vectors (From Hem, 1970).

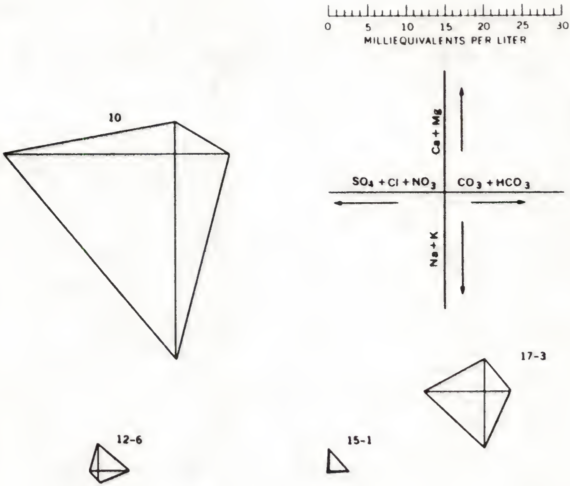



Figure 9. Four-component ion-concentration diagram (From Hem, 1970).

analysis data for critical study with respect to sources of the dissolved constituents in ground waters, modifications in the character of a water as it passes through an area, and related geochemistry. For the Piper trilinear program, ground water is viewed as containing only/merely three cations ($Mg^{+2}$, $NA^{+}$, and $Ca^{+2}$) and three anions (Cl, $SO_4$, and $HCO_3$). The triangular field at lower left contains the cation group percentage (Ca, Mg and Na), and the triangular field at the right contains the anion group percentage ($HCO_3$, $SO_4$, and Cl). Each point, one in each field, indicates the relative concentration of the three components. The central diamond-shaped field is used to show the general character of the water. Rays are projected upward from the triangle plots parallel to the triangle axes; the intersection of each pair of rays plots as a point on the diamond field. Thus, a ray is drawn parallel to the magnesium axis, and the other ray is drawn parallel to the sulfate axis. The intersection of these two rays is plotted, and this point characterizes the ground water of the sample location. Ground-water types can then be quickly discriminated by position within the diamond-shaped field (Figs. 10 and 11).

The circular, or pie diagram is perhaps the most flexible method to show quality of water. The radius of the circle is proportional to the total milliequivalents per liter (see Figure 12). Pie charts can be conveniently plotted on base maps to show the ground-water quality for the point source; however, they are time-consuming to construct, unless microcomputer plotting software is used.

Usually the literature search at the outset of the study will have produced published graphical representations of ground-water quality. Level I seldom requires plotting of raw data into Stiff diagrams, pie charts, trilinear diagrams, histograms, and so forth. Use these graphical representations, if already prepared by previous investigators, for the study area.

Ground-water quality for large areas (and perhaps for several aquifers) can be illustrated by superimposing available Stiff diagrams on a map of suitable scale. At Level I analysis, this should be done only if Stiff diagrams are already drawn and can readily be transferred to a map. Small changes in quality can be detected easily because the diagram produces a distinctive readily recognized shape. Consistent positioning of the diagrams on the map in relation to the point source can minimize confusion. Pie charts plotted on base maps can show ground-water quality for the point source, but this construction is time-consuming. Figures 13 and 14 show examples of use of pie charts and Stiff diagrams on hydrogeologic maps.

Trilinear diagrams are not usually good graphical representations to plot on maps showing water quality over a large area, because they take up a large amount of space. But they aid in interpreting the mixing of waters from different aquifers, especially when used as support with other kinds of interpretations. These diagrams alone cannot provide all the answers when studying water quality data.

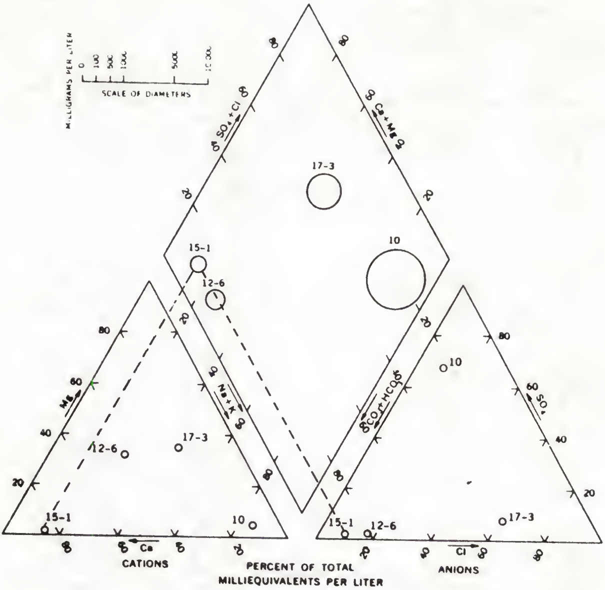



Figure 10. Piper trilinear diagram (From Hem, 1970).

(the circles plotted in the central diamond-shaped field have areas proportional to dissolved solids concentrations. The size of circle is determined by the dissolved solids concentration, in milligrams per liter, scaled at top left of the diagram. They are located by extending the points in the lower triangles into the diamond-shaped field to the points of intersection. For example, note location of sample 15-1.)

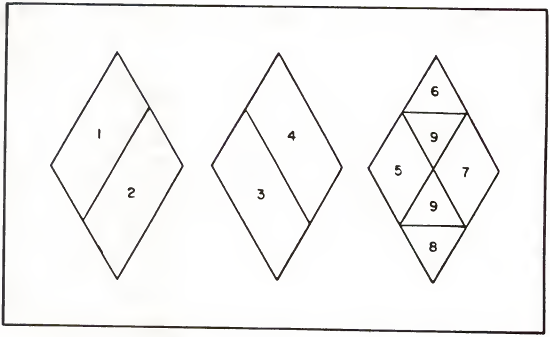



Figure 11. Subdivisions of diamond-shaped field of the Piper trilinear diagram

Explanation:

Area 1: Alkaline earths exceed alkalies.
Area 2: Alkalies exceed alkaline earths.
Area 3: Weak acids exceed strong acids.
Area 4: Strong acids exceed weak acids.
Area 5: Secondary alkalinity ("carbonate hardness") exceeds 50 percent--that is, chemical properties of the ground-water are dominated by alkaline earths and weak acids.
Area 6: Noncarbonate hardness ("secondary salinity") exceeds 50 percent.
Area 7: Noncarbonate alkali ("primary salinity") exceeds 50 percent--that is, chemical properties are dominated by alkalies and strong acids; ocean water and many brines plot in this area, near its right-hand vertex.
Area 8: Carbonate alkali ("primary alkalinity") exceeds 50 percent--here plot the ground-waters which are inordinately soft in proportion to their content of dissolved solids.
Area 9: No dominant cation-anion pair exceeds 50 percent (From Walton, 1970).

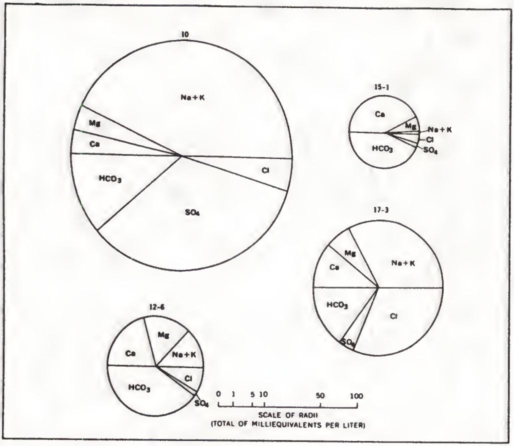



Figure 12. Water quality analyses represented by pie charts subdivided on the basis of total milliequivalents per liter (From Hem, 1970).

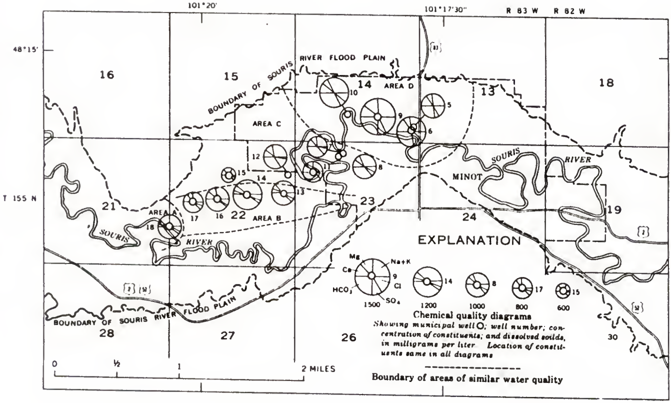


Figure 13. Example of pie charts on a hydrogeologic map depicting water quality of the Minot aquifer (From Ham, 1970).

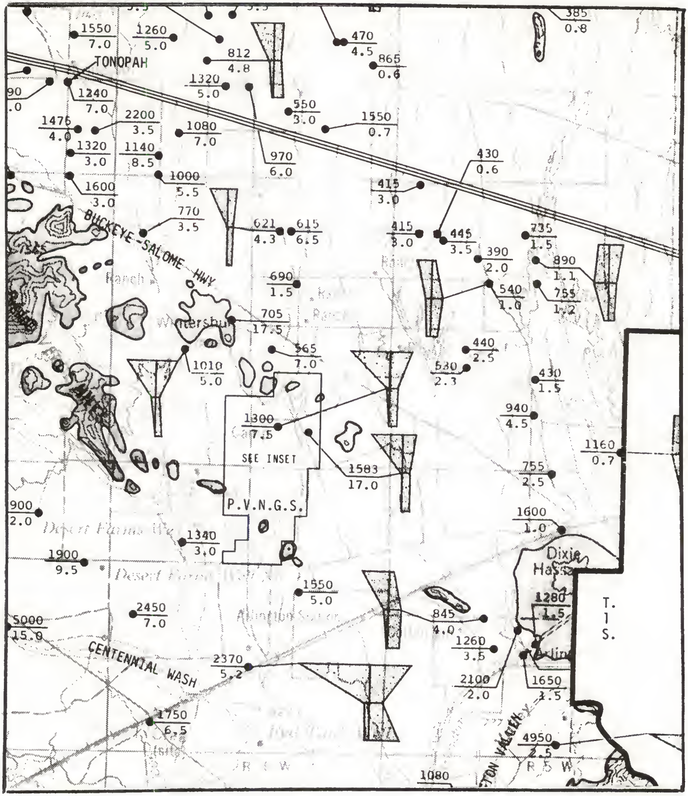



Figure 14. Example showing use of Stiff diagrams on a hydrogeologic map in Arizona to depict water quality trends (From Long, 1983).

## BASIN GROUND-WATER DEVELOPMENT

Development of a ground-water reservoir by pumping wells, or any other land-use activity that affects the reservoir, disturbs the natural inflow-outflow balance, or equilibrium. Major withdrawals commonly affect large areas of a ground-water reservoir; water levels drop to supply the localities of pumping. Continued pumping may reduce or stop natural discharge from the reservoir, and further, may reverse gradients and induce flow from streams or other surface water bodies that normally were avenues of discharge. All known springs flowing from the affected aquifer may need to be surveyed to determine if their flows are partially or wholly diminishing.

Concepts have been advanced to cope with the myriad options in developing ground-water reservoirs. The most common are sustained yield, safe yield, and optimum yield.

Sustained yield commonly refers to the quantity of water that can be withdrawn from a ground-water reservoir year after year without progressive depletion of water in storage. Withdrawal rates are maintained at less than or equal to the sum of changes in recharge and discharge. Its usage generally applies only to the availability of water at the maximum possible perennial rate, and not to water-quality, environmental, and other land and water-resources concerns. (Water Resources Council, 1980)

Safe yield is used similarly, and often synonymously, in reference to the magnitude of yield that can be maintained over a long period of time. However, safe yield may encompass safety or the long-term quality of the water as well as the yield, or the quality of streams in hydraulic connection with the ground-water reservoir, and still other hydrologic effects considered to be detrimental. Use of the term, therefore, requires establishment of allowable hydrologic impacts of the withdrawals. (Water Resources Council, 1980)

Optimum yield is a broader term referring to the "most favorable" withdrawal plan, taking into account not only hydrologic considerations but also the myriad social, economic, and legal factors in water management (Water Resources Council, 1980). Owing to the obvious wide range of applications, the words "optimum" and "most favorable" must be defined by the planner in terms of planning and management. (Water Resources Council, 1980)

In the planning of withdrawals, optimum yield choices may range from short-life, intensive extraction and perhaps conscious depletion of the reservoir, through longer-term sustained yield that extends the supply indefinitely but permits lesser rates of withdrawal, to the conservative extreme of maintaining the reservoir underdeveloped and secure for future needs. The planner must select the approach most favorable to established management goals. The hydrologist can assist but the decisions at this stage of planning are largely nonhydrologic (Water Resources Council, 1980).

The determination of optimum yield becomes infinitely more complex with escalating water-quality considerations, environmental and land management needs, water rights and other legal controls, and the social and political aspects of any major public matter. Indeed, optimal or most favorable usage of ground water may only be determinable politically. (Water Resources Council, 1980).

END

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# LEGISLATION, REGULATIONS AND EXECUTIVE ORDERS PERTAINING TO GROUND WATER RESOURCES

# INTRODUCTION

It is the policy of Bureau of Land Management (BLM) to comply with State requirements regarding the use and protection of ground water and to assist the States in their management of that resource. The role and responsibilities of the Bureau from the Federal vantage point are defined in a number of Federal Laws and Regulations as follows:

## Legislation

1. The Federal Land Policy and Management Act of 1976 (FLPMA), P.L. 95-87, (91 Stat 445, Aug 3, 1977)

Authorization to conduct investigations on resources on public lands do not specifically refer to ground water, but includes water resources protection in management provisions:

Sec. 102.(a)2: "The national interest will be best realized if the public lands and their resources are periodically and systematically inventoried and their present and future use is protected . . . ";

Sec. 102.(a)(8): "the public lands be managed in a manner that will protect . . . water resources;"

Sec. 201(a): "The Secretary shall prepare and maintain on a continuing basis an inventory of all public lands and their resources";

Sec. 302(c): This section of FLPMA provides authorization to revoke or suspend any land conveyance which grants use of public lands: if a condition of use has been violated that requires compliance with State or Federal . . . water quality standard or implementation plan, if the violation occurred on public land, or as deemed necessary to protect the environment.

### Title IV - Range Management

Sec. 401(b)(1): This section provides protection to the watershed and the water as a benefit of range development.

Sec. 603(a): "The review required by this subsection shall be conducted in accordance with the procedure specified in Section 3(d) of the Wilderness Act."

BLM Wilderness Management Policy, formulated in September 1981, (based on the Wilderness Act) addresses water resources in the following section:

Sec. 111.F: "Water Resources Management . . . The BLM's conclusions and recommendations in connection with proposals for new water resources developments will be based upon comprehensive, factual information developed by an environmental analysis . . . . Maintaining or enhancing water quality is of high priority in managing the wilderness resource."

Although ground water is not mentioned specifically, the interrelationships between surface water and ground-water resources are such that the terms water resources or water quality pertain to both types of resources.

2. Clean Water Act (CWA), P.L. 92-500, As Amended by P.L. 95-217, P.L. 95-576, P.L. 96-483, and P.L. 97-117; 33 USG 125. et seq.

The objectives of the CWA are the restoration and maintenance of the chemical, physical, and biological integrity of the nation's waters.

The Act provides for the protection of surface "navigable" water through Federally enforceable regulations, with emphasis on discharge of pollutants to surface waters.

Regulations for the protection of ground water are not included in CWA. Authority to protect ground water is vested in the States. However, the Act clearly delineates the Federal role in the protection of ground-water quality. Section 313 of the CWA requires Federal compliance with valid requirements of State and local governments to the same extent as any non-governmental entity. Sections 208 and 106 provide the Federal financial assistance and guidance to State and local governments for planning and management of ground-water resources. Section 208b.2 requires that individual States develop processes to identify and control:

* Surface mining and underground mining-associated pollution of surface water and ground water;

* Intrusion of salt water into fresh ground-water aquifers;

* The disposition of residual wastes that could adversely affect the quality of surface water or ground water;

* The disposal of pollutants on land or in excavations wherein adjacent surface water or ground-water quality degradation could ultimately result.

3. Safe Drinking Water Act (SWDA), P.L. 93-523, As Amended by P.L. 95-190, 42 USC 300 et seq.

The purpose of the Safe Drinking Water Act (SDWA), as amended, is to protect the public health and welfare by assuring that drinking water provided by public water systems be of adequate quality for human use. To accomplish this, the Act provides for:

* Establishment of primary national drinking water regulations setting forth mandatory maximum contaminant levels in drinking water supplied by public water systems.

* Establishment of secondary national drinking water regulations for public water systems. These regulations are not mandatory; however, they are recommended standards for the protection of public health.

* Protection of the quality of aquifers that serve as the principal source of drinking water for an area, which, if contaminated, would create a significant hazard to public health.

* Protection of underground sources of drinking water from injection of pollutants.

The SDWA provides for and encourages delegation of its authorities to the States which would assume primary responsibility for enforcing the provisions of the Act. Only in the event that a State failed to assume the responsibility would the enforcement be an EPA responsibility.

Under the provisions of Section 1447(a) of the Act, BLM is required to comply with both the substantive and procedural requirements of the Act. Specifically, Section 1447 directs that . . .

(a) Each Federal agency (1) having jurisdiction over any federally owned or maintained public water system or (2) engaged in any activity resulting, or which may result in, underground injection which endangers drinking water (within the meaning of section 1421(d)(2)) shall be subject to and comply with, all Federal, State, and local requirements, administrative authorities, and processes and sanctions respecting the provision of safe drinking water and respecting any underground injection program in the same manner, and to the same extent, as any non-governmental entity.

Under the provisions of the Act, BLM therefore is not responsible for primary enforcement of the requirements of the Act, but rather is regulated by those provisions. Thus BLM's role is to assist the States in their efforts to protect the quality of ground water which has present or potential use as an underground source of drinking water.

Section 1424(e) of the Act establishes a procedure which enables the EPA, either on its own initiative or on the basis of public petition, to designate an aquifer that has been determined to be the sole or principal drinking water source for an area as a "sole-source aquifer." The sole-source designation means no federally financially assisted project may be constructed on a site that would lead to contamination of the aquifer and the subsequent creation of "a significant hazard to public health."

Other ground-water related provisions are set forth in Sec. 1421, Underground Injection Control (UIC). The objective of these provisions is to prevent endangerment of drinking water sources by subsurface emplacement of fluids through well injection. States have the authority to implement the UIC program.

Applicability of the State UIC regulations to BLM as well as other Federal agencies is mandated in Sec. 1421(b)(1)(D). This section directs that the State programs shall apply ". . . to underground injections by Federal Agencies, and to underground injections by any other person whether or not occurring on property owned or leased by the United States."

In authorizing underground injection on Federal lands, BLM will require the injector to obtain a UIC permit from the State or EPA, as appropriate, and will supplement the conditions set forth in that permit as may be required to protect natural resources administered by BLM.

4. Resource Conservation and Recovery Act (P.L. 94-580), As Amended by the Solid Waste Disposal Act Amendments of 1980 (P.L. 96-482) USC 6901 et seq.

The Resource Conservation and Recovery Act (RCRA), as amended, provides Federal legislation and direction concerning the management of solid wastes, including hazardous wastes that present a hazard to human health or the environment when improperly managed. Various specific references in RCRA to underground waters clearly establish this Act as a major piece of legislation concerned with protecting ground-water quality.

RCRA also addresses coal mining and its regulation under the Surface Mining Control and Reclamation Act (SMCRA) of 1976. Section 100(c) of RCRA states that:

> (2) The Secretary of the Interior shall have exclusive responsibility for carrying out any requirement of subtitle C of this Act with respect to coal mining wastes or overburden for which a surface coal mining and reclamation permit is issued or approved under the Surface Mining Control and Reclamation Act of 1977. The Secretary shall, with the concurrence of the Administrator, promulgate such regulations as may be necessary to carry out the purposes of this subsection and shall integrate such regulations with regulations promulgated under (SMCRA).

The act waives the development and enforcement of regulations addressing mining wastes, pending completion of the study by EPA. Thus, no action has been taken by the Secretary to meet this requirement pending release of the mandated study.

Section 1002, which states the Act's objectives, is prefaced by a Congressional observation that "open dumping is particularly harmful to health, contaminates drinking water from underground and surface supplies and pollutes the air and the land."

Section 1004 defines the term "disposal" as the "discharge, deposit, injection, dumping, spilling, leaking or placing of any solid waste or hazardous waste or any constituent there of that may enter the environment or be admitted to the air or discharged into any water, including ground water."

RCRA emphasizes the primary role of the States in managing both conventional solid wastes and hazardous wastes. The legislation provided a Federal support role with minimal enforcement and regulatory process in regard to conventional solid wastes. Actual regulation and enforcement of solid-nonhazardous wastes was left to the individual States who were to follow broad guidelines established at the Federal level.

RCRA provides that Federal agencies are subject to, and must comply with, all Federal, State, interstate, and local requirements, both substantive and procedural (including any requirements for permits, reporting, or any provisions for injunctive relief and such sanctions as may be imposed by a court to enforce such relief), respecting control and abatement of solid or hazardous waste disposal in the same manner and to the same extent as any person is subject to such requirements.

Furthermore, BLM is required, by Sec. 6004 of the Act, to ensure compliance with both Federally issued guidelines for disposal of solid waste and with the purposes of the Act in the disposal of such waste. This specifically includes "protection of the quality of ground waters and surface waters from leachate."

Unlike much other Federal legislation, RCRA provides for joint and several liability of both owners and operators of a waste storage, treatment, or disposal site regulated under the hazardous waste management system. Thus, it is BLM's duty as "owner" to ensure compliance with RCRA requirements for a non-BLM-operated disposal facility authorized on the public lands.

It is important to note that State or local governments may add additional duties and responsibilities on BLM for protection of ground water from pollution by disposal of solid of hazardous wastes on the public lands, providing only that such requirement is germane, duly adopted and generally applicable. An example of such a situation is the State of California's recent decision to hold owners of solid (i.e., nonhazardous) waste disposal sites co-liable with the operators of such sites. It is the states' position that this ruling applies to agencies of Federal, State, and local government as well as private individuals. Under this rule, BLM is co-responsible for design, operation, closure and post-closure monitoring, and for any future liabilities arising from such responsibilities.

The 1984 amendments to the Act significantly increase the scope of existing controls and authorities of this legislation. They place stringent requirements on EPA for enforcement and the development of regulations. Specific guidance regarding the direction of regulation and enforcement initiatives is stated in the amendments. The legislative history of the amendments clearly states the intent of Congress to eliminate or minimize all threats from hazardous waste to the environment, particularly to the ground water. As a means of accomplishing its intent, the Congress has set forth 28 deadlines to be met by EPA and other affected Federal agencies, the States, and private parties involved with hazardous waste. All of the deadlines must be achieved by November of 1992, and 22 of them must be achieved by November of 1987. Over half of these deadlines affect BLM operations or activities under BLM jurisdiction. In most cases ground water is directly or indirectly involved.

5. <u>Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). P.L.96-510, 94 Stat 2767 et seq. (Dec. 11, 1980)</u>

This Act provided for the establishment of a tax-supported Hazardous Substance Response Trust Fund, popularly known as the "Superfund," to pay the cost of response actions for accidental releases of hazardous substances which are not waste materials, and hazardous waste releases; and for cleanup of abandoned or inactive facility sites, where responsibility for paying such costs cannot be determined, and where Federal lands are not involved. The Act provides additional authority for the control of hazardous substances that is broader than the authority covered by RCRA.

For example, regulations of CERCLA have been applied in remedial actions involving the removal or containment of mining wastes. At this time, RCRA does not specifically address mining wastes. Use of "Superfund" is limited to specific types of activities and is not available for compliance and cleanup of hazardous waste sites on Federal lands. Funds for actions involving Federal lands must be obtained through the appropriations process by the involved Federal agencies.

A second fund--the Post-Closure Liability Trust Fund--is established by CERCLA. This fund is supported by a $2.13 tax on each dry weight ton of hazardous waste received at a disposal site for permanent disposal. The funds will be utilized by the Federal government to pay costs associated with disposal site post-closure when Federal liability exists. Funding for post-closure liability is particularly important because it provides long-term protection to ground water through hazardous waste cleanups and ground water monitoring. However, the use of CERCLA post-closure liability funding on Federal lands is not provided for by the statute.

6. <u>TOXIC SUBSTANCES CONTROL ACT (TOSCA): P.L. 94-469, Oct. 11, 1976, 90 Stat. 2003; 15 U.S.C. 2601, et seq.; Amended by P.L. 97-129, Dec. 29, 1981</u>

This act protects human health and environment by requiring testing and use restrictions for chemical substances which may present an "unreasonable risk of injury to health or the environment." The stated intent of the act is to carry out regulatory efforts with a minimum impediment of economic efforts and innovation.

TOSCA was designed to be the umbrella act for all other legislation which addresses toxic substances impacts on the environment or human health. The Act addresses testing, manufacture and processing, R&D, and provides for support of State regulatory programs. TOSCA sets forth requirements governing disclosure of data, prohibited acts, judicial review, citizen civil actions and petitions, employee protection, and provides for special studies and development of test methods.

The major burden of the act is placed on manufacturers, processors, and distributors of potentially toxic substances. However, uses of such substances and therefore users, may also be regulated. The Act also provides for the regulation of the disposal of toxic substances produced under its jurisdiction. In EPA's current interpretation of the Act,

controls such as banning or restriction of use, disposal, or storage could be applied where ground-water contamination by potentially threatening chemicals has occurred or may be expected to occur.

The act requires that the Administrator of EPA be notified in advance regarding the manufacture of a new chemical or the processing or distribution of a chemical for a new use. Based on the information received, or lack thereof, the administrator is impowered to prohibit or limit manufacture, processing, or distribution to prevent an "unreasonable risk." The actions the administrator takes to address an established unreasonable risk must apply to one or more of the requirements set forth in Section 6. These requirements address a range of options including prohibiting, manufacturing, processing, or distributing of chemical substances, prohibiting or limiting of specific uses, and prohibiting or regulating disposal of chemicals. Monitoring and testing requirements, and requirements for posting of warning notices is also covered in the Act.

Section 20 addresses civil suits. It permits anyone to file civil suits against anybody, including governmental bodies within the limits of the eleventh Constitutional Amendment.

As in the case of RCRA, the sovereign immunity of Federal agencies and their employees is waived. The agencies, and employees, are required to comply with applicable Federal, State and local requirements to the same extent as any other person. Furthermore, as in the case of RCRA, BLM is considered to be the owner of any inactive or abandoned hazardous waste storage or disposal site on the lands under its jurisdiction. As such it may be jointly and severally liable with the operator for all damages and remedial costs associated with such sites.

The protection of ground-water quality from pollution by leachates resulting from accidental releases or from abandoned or inactive waste disposal sites is a major area of concern under CERCLA. Monies from the Superfund are available (off Federal lands) for ground-water investigation, protection and cleanup. A similar situation exists as concerns the Post-Closure Trust Fund.

7. <u>Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) P.L. 92-516, 86 stat. 973-999; as amended by P.L. 94-140, Nov. 28, 1975; P.L. 95-396, Sept. 30, 1978; P.L. 96-539, Dec. 17, 1980; and P.L. 98-201, Dec. 2, 1983</u>:

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) regulates the manufacture, distribution, use, and disposal of pesticides. The primary emphasis of the Act is on the labeling of pesticides and the registration of pesticides for specific uses.

The law provides for the regulation of the use of pesticides allowing a general use classification and providing for restricted use where appropriate. In the case of restricted use pesticides, users and applicators must be certified. A restricted use pesticide must be applied by an applicator who is certified according to the requirements of this Act and/or the appropriate State Act.

In EPA's current interpretation of the Act, use restrictions could be applied where ground-water contamination by pesticides has occurred or may be expected to occur.

The Act establishes requirements for the regulation of pesticides through record keeping, and provides mechanisms for removal/seizure of pesticides. The exemption for Federal and State agencies under the 11th ammendment of the constitution, however, is not waived in the Act. The Act provides both civil and criminal penalties for violations. Civil penalties of $1000 to $3000 per day are provided by Section 14 for violation of the Act. In addition, the section provides for criminal penalties of $1000 and/or 30 days in jail to $25,000 and/or one year in jail. Unauthorized disclosure of confidential material carries a $10,000 fine and/or up to 3 years in jail.

Federal or State agencies may be exempted from requirements of this Act by the Administrator of EPA only when emergency conditions are determined to exist.

8. Surface Mining Control and Reclamation Act (SMCRA) (P.L. 95-87, 91 Stat. 445, 30 U.S.C. 1201 et seq. (Aug. 3, 1977)

The intent of the Surface Mining Control and Reclamation Act is to prevent "imminent danger to the health and safety of the public" and "significant, imminent environmental harm to land, air or water resources," that might be caused by both surface and underground mining operations.

The law requires the completion of hydrogeologic studies prior to the covering or burial of acid-forming and toxic-forming waste materials, as well as when any mine is to be filled with any type of waste material. Also, the mine operator must demonstrate that the activity will only minimally disturb the hydrologic balance of the area. Further, if the mining operation contaminates, diminishes, or interrupts the ground-water or surface water supply of an adjacent land owner, the mining company must replace the water supply.

Additional requirements by the secretary regarding toxic wastes may result from SMCRA's integration with RCRA (discussed under RCRA).

Although SMCRA is administered by the Office of Surface Mining, BLM is involved with the implementation of that Act on Federal lands. BLM's ground-water responsibilities involve evaluation of the probable effects of mining and reclamation practices upon the ground-water system. Specific citations concerning these responsibilities are found in Secs. 507(b)(11), (14), and (15); Secs. 508(a) (12) and (13); Sec. 510(b)(5); Sec. 515(b)(10) and (14); and, Sec. 522(a)(3)(c).

9. <u>Uranium Mill Tailings Radiation and Control Act of 1978 (UMTRCA) P.L 95-604, Nov. 8, 1978; 92 stat. 3021; as amended by P.L. 95-106, Nov. 9, 1979, 93 stat. 799; and P.L. 97-415, Jan. 4, 1983, 96 stat. 2078.</u>

The Uranium Mill Tailings Radiation Control Act (UMTRCA) regulates mill tailings at active and inactive uranium mill operations that present a hazard to public health. The Act provides that efforts are to be made to stabilize, control, and dispose of uranium mill tailings in an environmentally sound and safe manner.

The Act provides (1) a program of assessment and remedial action at abandoned mill sites, and (2) a program regulating mill tailings during processing at active processing mills.

TITLE I--REMEDIAL ACTION PROGRAM

This section of UMTRCA addresses remedial action at abandoned sites. A list of processing sites at specific locations are required to be designated. The Act requires cooperative agreements with States and Indian tribes, and lands acquisition for public health protection and waste disposal.

When remedial action is carried out, the technology used must permit compliance with the general standards promugated by the Administrator of EPA. Under Sec. 275(c) of the Atomic Energy Act of 1954, these actions must assure the ". . . safe and environmentally sound stabilization of residual radioactive materials, consistent with existing law." The Secretary of Energy is responsible for assuring such technology is used.

Violation of the provisions of Title I or any cooperative agreement entered into pursuant to this title is subject to a maximum civil penalty of $1000 for each day of violation.

TITLE II--URANIUM MILL TAILINGS LICENSING AND REGULATIONS

This title addresses the handling and disposal of waste materials and the licensing of those who handle such materials at active sites. It requires licensees to comply with decontamination, decommissioning, and reclamation standards prescribed by the Atomic Energy Commission (now the Dept. of Energy). It also requires that the Commission assure that licensees will maintain property and materials ". . . in such a manner as will protect the public health, safety and the environment." When appropriate, the transfer of land and interests affected by the license to the Federal or State government, prior to terminating the license, to protect the public health, welfare and the environment is authorized. In addition, ". . . the Commission may require Federal or State agencies . . . to undertake such monitoring, maintenance, and emergency measures as are necessary to protect the public health and safety. In addition, the Commission is given the authority " . . . to require the Secretary or other Federal agency or State having custody of such lands and interest . . . to undertake such monitoring" (Sec 202). The Act gives the

Commission authority to establish standards and instructions regarding: (1) adequate bonding or surety; (2) long term maintenance and monitoring of sites; and (3) financial arrangements by the licensees for long term maintenance and monitoring prior to termination (Sec 203).

Section 204 of the Act provides for cooperation with States on the issues of active sites and their by-product material and the development of State agreements. Such cooperation and agreements include ". . . compliance with standards which shall be adopted by the State for the protection of public health, safety, and the environment . . .", provided they are equivalent or more stringent than standards promulgated by the Environmental Protection Agency (EPA). Further, the established State standards will provide for public comment, written environmental analysis, and an assessment of impacts including ground-water impacts.

The authorities respecting by-product material discussed in Section 205, require the Commission to ensure that the management of such material is conducted in such manner as to protect the public health, safety, and the environment in conformance with the applicable general standards promugated by the EPA; and are comparable to requirements under the Solid Waste Disposal Act. Section 275 (b) (2) states that generally applicable standards promulgated pursuant to this subsection for non-radiological hazards shall provide ". . . protection of human health and the environment consistent with the standards required under Subtitle C of the Solid Waste Disposal Act . . . ."

Violation of this title is subject to existing Civil penalties defined under Section 234.

10. Nuclear Waste Policy Act of 1982, P.L. 97-425, Jan. 7, 1983, 96 stat. 2201.

The Act consists of three titles under which provisions are made for specific kinds of wastes produced by specific types of activities. Regulations pertain to storage and disposal of high-level radioactive wastes, spent nuclear fuel, and low-level wastes from civilian sources in ". . . any repository not exclusively used for the disposal of high-level radioactive wastes or spent nuclear fuel which results from atomic energy defense research and development." The Act does, however, give consideration to disposal of waste resulting from defense activity.

Title I contains provisions for the disposal of high-level radioactive wastes and spent nuclear fuel. This title contains the most comprehensive coverage of nuclear waste disposal policy; therefore, the provisions of Title I will be discussed in detail. Title II applies to research facilities, and the pertinent provisions will be cited which do not duplicate provisions under Title I. Title III contains provisions for radioactive waste emission plans, a discussion of The Nuclear Waste Fund, and alternate plans for financing storage and disposal sites.

TITLE I--Storage and Disposal of High Level Radioactive Waste, Spent Nuclear Fuel, and Low-Level Radioactive Waste

Purpose:

(1) "to establish a schedule for siting, construction, and operation of repositories that will provide reasonable assurance that the public and the environment will be adequately protected from high-level radioactive waste and spent nuclear fuel as may be disposed of in a repository;

(2) to establish Federal responsibility and a definite Federal policy for the disposal of such waste and spent fuel;

(3) to define the relationship between the Federal Government and the State Governments with respect to the disposal of such waste and spent fuel; and

(4) to establish a Nuclear Waste Fund, composed of payments made by the generators and owners of such waste and spent fuel, that will ensure that the costs of carrying out activities relating to the disposal of such waste and spent fuel will be borne by the persons responsible for generating such waste and spent fuel."

Guidelines for Environmental Assessment (Title I): Each nomination for a candidate site must be accompanied by an Environmental Assessment which includes the following:

(1) an evaluation by the Secretary of Energy of suitability of the site for characterization under the guidelines;
(2) an evaluation by the Secretary of Energy of suitability of the site for development as a repository under each such guideline that does not require site characterization as a prerequisite;
(3) an evaluation by the Secretary of Energy of the effects of the activities of site characterization on the environment and on public health and safety;
(4) an evaluation by the Secretary of Energy which consist of a reasonable comparison of the site with other sites and potential locations for sites;
(5) a description of the decision process used to select a site; and;
(6) an assessment of the local and regional impacts of the site.
(7) Requirement of the Secretary of Energy to use all available data on the site, including geological, geophysical, geochemical, and Hydrological information; and authorization to obtain drill hole data when absolutely necessary by drilling of holes no larger than 6" diameter.

The site selection process sets forth specific procedures for authorization of repositories, which comply with general technical

standards for the protection of the environment from radiation that were developed under mandate by the Environmental Protection Agency. The procedures include for each site being considered:

(1) Consultation with affected States or Indian tribes, along with financial assistance when needed;
(2) Cooperative agreements with local Governments; and
(3) Local Public hearings.

Title I and II of the Act contain a narrow interpretation of NEPA in the site selection process. Under both titles, conditions which require an Environmental Assessment or an Environmental Impact Statement are spelled out. Mandatory subject matter for EAs and EISs for nuclear repository sites is given.

Although no EIS is required for preliminary site selection, EISs are required for long-term storage sites under Title I and research sites under Title II.

Once the site selections have received final approval, an EIS addressing specific portions of the active construction and development phase is required.

TITLE II -- Research, Development, and Demonstration Regarding Disposal of High Level Radioactive Waste and Spent Nuclear Fuel.

Purpose:

(1) to provide direction to the Secretary with respect to disposal of high-level radioactive waste and spent nuclear fuel;

(2) to authorize the Secretary to provide for a focused and integrated high-level radioactive wastes and spent nuclear fuel disposal research and development program;

(3) provide for an improved cooperative role between the Federal Government and the States, units of local Government, and affected Indian tribes, in the siting of test and evaluation facilities.

The manner in which issues are addressed under the above stated purpose of Title I and Title II are duplicative unless stated otherwise. These issues include: environmental assessments, environmental impact statements, waivers of EIS's, land acquisition, and published hearings.

11. Wild and Scenic Rivers Act, P.L. 90-548, Oct. 2, 1968, 82 stat. 906 and as amended.

Portions of this Act provide for control of activities on land adjacent to rivers which could cause or contribute to pollution of waters, or could result in degradation of water quality through erosion and

siltation of riverbank lands, and contamination of ground-water sources feeding the river.

Section 1271. Congressional declaration of policy
This section of the Act refers to protection of the environment of wild & scenic rivers and to preservation of the "free flowing condition to protect the water quality of such rivers ...".

Section 1280. Federal Mining & Mineral Leasing Laws
This subsection of the Act provides that regulations pertaining to prospecting and mining operations under (1) mineral leasing, licenses or permits, or (2) patented mining claims should "... provide safeguards against pollution of the river involved ...".

Section 282(c). Water Pollution
Federal Agencies having administrative responsibility for any portion of the wild and scenic river system are required to cooperate with State agencies for the control of pollution of the water of the river.

12. GEOTHERMAL STEAM ACT OF 1970, P.L. 91-581, Dec. 24, 1970, 84 stat. 1566

The Act provides for the protection of water resources by Federal regulation, and by reference to authorities vested in the State and local Governments. Maintenance of the natural condition of the waters is an integral part of management, for which specific guidelines are established in subparts of the document, as follows:

* Regulations to prevent degradation of water quality including: ground water; damage to fish and their habitat; or pollution of the surface water and ground water.

* Specifically required during operations are ". . . collection of data concerning the existing . . . water quality", to include well records which contain chemical analyses of steam or water in each formation.

* Well wastes and drilling fluids from pits must not be allowed to pollute surface or subsurface waters. Saline waters must be prevented from invading fresh water aquifers.

Provisions for enforcement include: annual report of compliance; authority to shut down operations for non-compliance of leasing stipulations; and a permit process to allow reinjection of Geothermal waste fluids into ground-water zones.

## Executive Orders

1. Executive Order 11514--Protection and Enhancement of Environmental Quality, Mar. 5, 1970 by Executive Order 11991, May 24, 1977

Ground-water issues are inferred in the policy statement:

> "Section 1. Policy. The Federal Government shall provide leadership in protecting and enhancing the quality of the Nation's environment to sustain and enrich human life. Federal agencies shall initiate measures needed to direct their policies, plans and programs so as to meet national environmental goals." (underscoring added).

Section 2. Responsibilities of Federal Agencies:

The authority to conduct ground-water investigations is ordered indirectly through general directives in this section. Federal agencies shall:

(a) Monitor, evaluate, and control on a continuing basis their agencies activities so as to protect and enhance the quality of the environment. Such activities shall include those directed to controlling pollution and enhancing the environment and those designed to accomplish other program objectives which may affect the quality of the environment. Agencies shall develop programs and measures to protect and enhance environmental quality and shall assess progress in meeting the specific objectives of such activities. Heads of agencies shall consult with appropriate Federal, State and local agencies in carrying out their activities as they affect the quality of the environment .

(b) Engage in exchange of data and research results, and cooperate with agencies of other governments to foster the purpose of the Act.

2. EXECUTIVE ORDER 11735 , Aug. 3, 1973, 38 FR 21243, as amended by Executive Order 12418, May 5, 1983, 48 FR 28091, delegating functions of the President under Sec. 311 of the Federal Water Pollution Control Act, as amended.

Executive Order 11735 implements the requirements of Section 311 of the Federal Water Pollution Control Act, later called the Clean Water Act. It establishes the executive authorities and procedures for addressing oil and hazardous waste spills affecting navigable waters of the U.S. The definitions used traditionally include ground water when considering potential impacts. The National Contingency Plan and emergency task forces are established by this E.O. and all Federal agencies with appropriate expertise are obligated to provide assistance.

3. EXECUTIVE ORDER 11990, Protection of Wetlands, May 24, 1977, 44 FR 1955

This Executive Order directs all agencies to provide leadership and take action to minimize the destruction, loss or degradation of wetlands in accordance with NEPA. It covers aspects of Federal activities affecting wetlands including land management, facilities development, and regulations on licensing activity. The agencies are requested to minimize the impacts of Federal actions on wetlands and their related beneficial effects, such as ground-water recharge. In carrying out any activities affecting wetlands, Federal agencies must consider such factors as: public health, safety, and welfare including such things as water supply and quality, recharge and discharge areas for ground water, pollution, etc. Other environmental concerns and uses of wetlands in the public interest must also be concerned.

4. EXECUTIVE ORDER 12088 - FEDERAL COMPLIANCE WITH POLLUTION CONTROL STANDARDS, OCTOBER 13, 1978

This Order directs the Executive agencies to take all necessary actions for the prevention, control, and abatement of environmental pollution as regards activities and facilities under the control of those agencies. The Order further directs those agencies to comply with both the procedural and substantive requirements of applicable pollution control standards, including RCRA, CERCLA, CWA, SDWA and State and local laws and rules to the same extent as any other person is required to do so. Thus, the order waives Sovereign Immunity for all environmental laws addressing pollution control even though sovereign immunity is not specifically waived by law (Legal Aid Society of Alameda county vs Brennan 608 F.2d 1319, 1329-31C 9th Cir. 1979 and Sierra Club V Peterson, 705 F.2d 1475 (1983).

Compliance with the Order will therefore require BLM to comply with both State and local ground-water requirements and the requirements of pertinent Federal laws and regulations as they concern ground water.

5. EXECUTIVE ORDER 12316 - RESPONSES TO ENVIRONMENTAL DAMAGE, Aug. 14, 1981, 46 FR 42237

This Executive Order (EO), which revokes EO 12286, addresses the National Contingency Plan (NCP) and superfund under CERCLA. The EO responds to the mandate of CERCLA and modifies the NCP established by the Clean Water Act to conform with the NCP requirements set forth in CERCLA.

A National Response Team (NRT) composed of representatives from 12 specified agencies including Interior, Defense, State, Justice, and EPA will be organized to respond to hazardous waste concerns. Specific areas of responsibility are assigned to the various agencies participating on the National Response Team (NRT). The agencies with membership on the NRT are obligated to provide critical resource assessment to the NRT if requested.

This EO also addresses natural resources and the assessment of damage to them. Four agencies are designated primary Federal Trustees of natural resources:

(1) Department of Defense
(2) Department of the Interior
(3) Department of Agriculture
(4) Department of Commerce.

Interior is given overall responsibility for Natural Resources under Federal jurisdiction. This responsibility includes the development of regulations for conducting natural resource damage assessments, including the assessment of damage to ground water.

This order establishes procedures to manage the Hazardous Substance Trust Fund ("superfund"), enacted by section 221 of CERCLA. It sets up a budget task force comprised of representatives of agencies having responabilities under this Executive Order or in CERCLA. The task force will recommend to the Administrator allocations for use of the Hazardous Substance Trust Fund. A major use of the fund, historically, has been for ground-water protection and restoration.

6. EXECUTIVE ORDER 12372 - INTERGOVERNMENTAL REVIEW OF FEDERAL PROGRAMS, July 14, 1982, 47 FR 30959

This Executive Order replaces OMB circular A-95 and emphasizes the reliance on State and local processes for the review and coordination of Federal financial assistance and direct development. It requires Federal agencies to provide opportunities for consultation by elected officials of State and local governments which would be directly affected by Federal action. To the extent permitted by law, the Federal agencies shall utilize the State process for determining the official view, communicating with elected officials early in the planning process, accommodating State and local concerns, and coordinating views between States regarding interstate impacts.

## Regulations

1. 43 CFR 3809 Surface Management

Authority for the regulations in this subpart are found in the Federal Land Policy and Management Act (FLPMA), and the Wild and Scenic Rivers Act.

The purpose of these regulations is to establish procedures to prevent "unnecessary or undue degradation to Federal lands which may result from operations authorized by the mining laws."

Section 3809.0-3 (b) This part sets forth authority from FLPMA that requires the Secretary to "take any action, by regulation or otherwise, to prevent unnecessary or undue degradation of the Federal lands, [and] provide for enforcement of those regulations...".

Section 3809.0-3(d). This section relates to Section 9 of the Wild and Scenic Rivers Act, which provides that "regulations issued shall, among other things, provide safeguards against pollution of the rivers involved ... "

Section 3809.0-5(K) This part provides for mitigation of surface disturbance during operations, ". . .taking into consideration the effects of operations on other resources and land uses, <u>including those resources and uses outside the area of operations</u>."(underscoring added).

Section 3809.1-3(4)(iii) This part provides that reclamation shall include " ...measures to isolate, remove, or control toxic materials; "

Section 3809.2-2(b): Other requirements for environmental protection -- "... All operators shall comply with applicable Federal and State water quality standards, including the Federal Water Pollution Control Act.as amended (30 U.S.C. 1151 et seq.)".

2. <u>Coal Management Regulations (Amendments to Bureau of Land Management Coal Program Regulations), 43 CFR, Part 3400, (47 Fed. Reg. 33114, July 30, 1982 - eff. Aug. 30, 1982)</u>.

Coal regulations were published under the authority of the Mineral Leasing Act of 1920 as amended and supplemented; the Federal Land Policy and Management Act of 1976; the Surface Mining Control and Reclamation Act of 1977; and the Multiple Mineral Development Act.

Ground-water considerations are an integral part of the analyses involved prior to competitive leasing (Subpart 3420), preference right leases (Subpart 3430) and during environmental considerations (Subpart 3460). The effect of proposed mining and reclamation practices must be evaluated in terms of their effect on ground water in order to mitigate adverse effects.

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9. Index to advance material available from current topographic mapping in progress by States (USGS)
10. Index to advance material available from the orthophoto mapping program by States (USGS)
11. Index to Landsat coverage (USGS)
12. Index to serial photography by States (USGS)
13. Catalog of information or water data (USGS)

B. State and Other Sources

1. "Bibliography of North American Geology"
2. State Index of geologic maps
3. State Index of geologic reports
4. GEO REF of American Geological Institute

V. TABULAR OR MACHINE READABLE DATA

A. Water Quantity Subcategory

1. USGS WATSTOR printouts
2. State Engineer water rights printouts (ground water)
3. State resource agency tabulations of available ground-water quantity information
4. BLM records

B. Water Quality Subcategory

1. USGS WATSTORE printouts
2. USEPA STORET printouts
3. State Resources agency printouts

C. Water Use

1. USGS ground water use tabulations
2. State water engineer water use tabulations
3. Other State resource agency water use (ground-water data base)

## III. BOOKS, REPORTS, AND OTHER PERIODICALS

### A. Ground Water and Geology Combined

1. USGS Bulletins and Circulars
2. Pertinent environmental impact statements
3. USGS professional papers (Geology)
4. USGS open-file reports (geology and ground water)
5. GeologicalSociety of America Bulletin
6. State geological survey reports, bulletins, and circulars
7. State geological survey open-file reports
8. BLM internal reports (e.g., EMRIA reports)
9. USGS open-file geologic maps (these are usually preliminary editions)
10. Reports on mining districts available from USGS and some state agencies (contained in USGS bulletins and professional papers)
11. USGS water supply papers
12. USGS reports on water resources data by states (published annually)
13. National Handbook of Recommended Methods for Water Data Acquisition (USGS)
14. State reports on ground water and aquifers (Dept. of Environmental Quality, etc.)
15. BLM ground-water investigations and well reports (e.g., well site investigations, EMRIA reports)
16. Coal hydrology reports
17. USGS Regional Aquifer-System Analysis (RASA) Program Reports
18. American Association of Petroleum Geol. Bulletins (information on structural geology)
19. Catalogue of information on water data (USGS)
20. List of water resources investigations, by states (USGS)
21. Published list of state water resources investigations
22. Printouts of NAWDEX data
23. List of US EPA-published water resource documents (published quarterly)

## IV. ABSTRACTS, BIBLIOGRAPHIES (INCLUDES GEOLOGY, GROUND WATER AND ANY RELATED SUBJECTS AND INDEXES

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2. "Publications of the Geological Survey" (USGS)
3. "Publications of the Geological Survey" (yearly USGS)
4. "New Publications of the Geological Survey" (monthly by USGS)
5. USGS list of geologic and water supply reports and maps by States
6. Geologic maps indexes by States (USGS)
7. Index to topographic maps in the United States by State (USGS)
8. Index to topographic maps on the United States, 1:250,000 and 1:1,000,000 scales (USGS)

# SOURCE LIST OF INFORMATION NEEDED IN GROUND-WATER INVESTIGATIONS

## I. INTRODUCTION

Appendix C has been developed as an aid in locating and assembling currently existing basic ground-water data and information contained in various agency data systems, files, reports, and other published and unpublished documents. The purpose of this appendix is to assist those less familiar with this specialty field in developing a basic data base and to provide a convenient data-source checklist for those more conversant with the field. All questions related to the acquisition availability or value of individual data items or related to the adequacy of a field office data base may be directed to the BLM staff hydrogeologist, Division of Resource Systems, at the Denver Service Center. The BLM hydrogeologist at the Denver Service Center should be contacted early in the data assemblance effort for assistance if needed.

## II. MAPS

### A. Geologic

1. USGS Geologic Quadrangle maps (GQ series)
2. USGS Geophysical maps (GP series)
3. USGS minerals investigations maps (MF and MR series)
4. USGS miscellaneous field studies and investigations maps (MF and I series)
5. USGS oil and gas investigations maps charts and maps (OC and OM series)
6. USGS coal investigation maps (C series)
7. USGS special geologic maps
8. USGS State geologic maps
9. USGS surface management and surface minerals maps (1:1,000,000 scale)
10. USGS separate map inserts from bulletins, professional papers, or water supply papers
11. USGS open file maps
12. State-published geological maps (generally 1:250,000 or 1:500,000 scale are available)
13. State geological survey office open-file geological maps

### B. Ground Water

1. USGS hydrologic atlases (HA series)
2. USGS open-file ground-water maps
3. State-published maps of aquifers
4. State-open-file ground-water occurrence and quality maps
5. State ground-water use maps
6. USGS water resource investigations (WRI series)

SELECTED DATA BASES FOR GROUND WATER INVESTIGATIONS

| Data Base Name | Subject Coverage | Coverage Dates | Update Frequency | Sponsoring Agency | Comments |
|---|---|---|---|---|---|
| AGRICOLA | Covers worldwide journal and monographic literature in agriculture and related fields, including general agriculture and rural sociology; animal science; forestry and plant-related areas; entomology; and agricultural engineering. Includes agriculture Canada. | 1970-Pres. | Over 1 million citations, Monthly updates | U.S. National Agricultural Library | Citations only |
| APTIC | Covers most sources for citations concerning all aspects of air pollution, its effects, prevention and control. | 1966-Oct. 1978 | 89,000 citations | Manpower and Technical Information Branch EPA. | Abstracts |
| ASI | American Statistics Index covers statistical publications containing the entire spectrum of social economic and demographic data collected and analyzed by all branches and agencies of the U.S. government. | 1973-Pres. (some material from 1960's). | Over 55,000 citations, monthly updates. | Congressional Information Service, Inc. | Abstracts |
| BIOSIS PREVIEWS | Covers all aspects of the life sciences, drawing upon all original published literature for citations. Corresponds to Biological Abstracts/RRM. | 1969-Pres. | 2,265,000 records; Monthly updates. | Information Service | Bioscience only |
| CA CONDENSATES 70-71 | Covers all aspects of the chemical literature both applied and theoretical. Corresponds to Chemical Abstracts. | 1970-1971 | 585,000 records | Chemical Abstracts Service | Citations only |
| CA CONDENSATES/ CASIA | Gives general subject index headings and CAS registry numbers for documents covered by CA condensates. | 1972-Pres. | Corresponds to CA Condensates after initial file load. Bi-weekly updates. | Chemical Abstracts Services | Description and identifiers only |

SELECTED DATA BASES FOR GROUND WATER INVESTIGATIONS (Cont.)

| Data Base Name | Subject Coverage | Coverage Dates | Update Frequency | Sponsoring Agency | Comments |
|---|---|---|---|---|---|
| CAB ABSTRACTS | Comprehensive file of agricultural information pertaining to all significant material and covering every aspect of crop and animal science. | 1973-Pres. | Over 966,000 items. Monthly updates. | The Commonwealth Agricultural Bureau | Abstracts |
| CANCERLIT | (Formerly Cancerline). Contains information on various aspects of cancer taken from over 3,000 U.S. and foreign journals as well as selected monographs, papers, reports and dissertations. | 1963-Pres. | Over 100,000 Abstracts of Articles; Updated monthly | National Cancer | Abstracts |
| CHEMDEX | Chemdex is based on the CA Registry Nomenclature File, which is a repository for names associated with substances that have been registered by Chemical Abstracts. In addition to CA's rigorous nomenclature data, this file contains registry numbers, molecular data, this file contains registry numbers, molecular formulas, synonyms and ring system information. | Contains all substances cited in the CA Abstracts volumes since 1972. | 694,461 substances; quarterly updates | Chemical Abstracts Service of the American Chemical Society | |
| CHEMLINE | Chemline is an outline chemical dictionary file providing a mechanism for searching and retrieving chemical substance names. It contains 439,812 records for chemicals that are identified by chemical abstracts service registry numbers and are cited in either Toxline, Toxback, TDB, or RTECS. | | Irregular updates | National Library of Medicine | |
| CHEMNAME | Contains CAS registry numbers, CA substance index names, molecular formulas, chemical name synonyms and periodic classification terms for chemical substances. | Corresponds to CASIA | 737,000 substances; quarterly updates | Chemical Abstracts Service and Lockhead | Gives names and CAS regstry numbers only |
| CLAIMS/CHEM | U.S. chemical and chemically-related patents plus some foreign equivalents. | 1950-1970 | 265,000 citations. | IFI/Plenum Data Co. | Citations |

SELECTED DATA BASES FOR GROUND WATER INVESTIGATIONS (Cont.)

| Data Base Name | Subject Coverage | Coverage Dates | Update Frequency | Sponsoring Agency | Comments |
|---|---|---|---|---|---|
| COMPREHENSIVE DISSERTATION ABSTRACTS | Interdisciplinary listing of almost all doctoral dissertations accepted since 1861 by accredited degree granting institutions in the U.S. plus some non-U.S. universities. | 1861-Pres. | Over 648,000 citation. monthly updates | Xerox University Microfilms | Citations only |
| CONFERENCE PAPERS INDEX | Covers approximately 1,000 scientific and technical meetings worldwide and the 100,000 papers presented. | 1973-Pres. | 715,000 records monthly updates | Data Courier | |
| EDB | The energy data base covers all information of interest to DOE in almost every area of research. | 1974-Pres. (Contains material back to late 1800's | 98,700 citations. 5,000 items semi- | DOE Technical Information Center monthly | Abstracts (after June 1, 1976) |
| EIS INDUSTRIAL | Information on 130,000 establishments operated by 67,000 firms with current annual sales of over $500,000 describing employment, sales, market share and production. | Current | 140,000 records; replaced 3 times/year | Economic Information Systems | Citations only |
| EMI (EMIC) | Environmental mutagens - information concerning chemical mutagen research. | 1976-Pres. | | DOE-TIC | Abstracts |
| ENVIRONMENTAL PERIODICALS BIBLIOGRAPHY (EPB) | Covers the very board field of general human ecology, atmospheric studies, energy, land resources, water resources and nutrition and health from 300 periodicals. | 1973-Pres. | Over 158,000 records. Bi-monthly updates | Environmental Studies Institute | Citations |
| EXCERPTA MEDICA | Covers all fields of medicine plus extensive coverage of the drug and pharmaceutical literature and other areas such as environmental health and pollution control. | June 1974-Pres. | 1,160,000 records, monthly updates | Excerpta Media | Abstracts |

SELECTED DATA BASES FOR GROUND WATER INVESTIGATIONS (Cont.)

| Data Base Name | Subject Coverage | Coverage Dates | Update Frequency | Sponsoring Agency | Comments |
|---|---|---|---|---|---|
| FEDERAL INDEX | Substantive comments from the Congressional Record, Federal Register, Presidential documents, and the Washington Post. Trends and developments in Washington are provided by citations to the Code of Federal Regulations, the US Code, public laws, congressional bills, and resolutions and reports. Coverage extends to proposed rules, regulations, bill introductions, speeches, hearings, roll calls, reports vetoes, court decisions, executive orders, contract awards, etc. | Oct. 1976-Pres. | 130,000 citations, monthly updates | Predicasts | Citations only |
| FEDERAL REGISTER | Contents correspond to the Federal Register Abstracts | March 1977-Pres. | Weekly | Capital Services | Citations |
| GEOARCHIVE | Covers geoscience information. Mineral and petroleum production and resources and new names typify the data currently added to the fields of geophysics, geochemistry, geology, paleontology and mathematical geology. | 1969-Pres. | 290,000 citations; monthly updates | Geosystems of London | Abstracts |
| GEOREF | Covers geosciences literature from 3,000 journals, plus the geosciences conferences and major symposia and monographs in all areas of the geosciences. | 1961-Pres. | 360,000 items; 4,000 records/month | American Geological Institute | |
| IPA | Information on all phases of development and use of | 1970-Pres. | 43,000 items 500-600 added monthly | American Society of Hospital Pharmacists | |
| MEDLINE | Bibliographic citations to worldwide medical literature corresponds to Index Medicus. | 1976-Pres. | Over 815,000 citations | National Library of Medicine | Abstracts when available |

SELECTED DATA BASES FOR GROUND WATER INVESTIGATIONS (Cont.)

| Data Base Name | Subject Coverage | Coverage Dates | Update Frequency | Sponsoring Agency | Comments |
|---|---|---|---|---|---|
| MGA | Covers meteorological and geoastrophysical research published in both foreign and domestic literature. Based on Meteorological and Geoastrophysical Abstracts. | 1970-Pres. | 43,500 citations, irregular updates | American Meteorological Society | Abstracts |
| NAWDEX | National Water Data Exchange - Contains information concerning water data availability, source and some major data characteristics. | 1700's-Pres | As necessary data from 61,500 sites stored. | U.S. Geological Survey | |
| NBI | National Biomonitoring Inventory - Information on on-going biomonitoring projects in the U.S. | Current | As necessary | DOE-TIC | Abstracts |
| NCC | National Climatic Center - Contains historical and current weather information and related data. The data is generated by: NOAA's Weather Service; the U.S. Navy and U.S. Air Force weather Service; the Federal aviation Administration; the U.S. Coast Guard; and cooperative observers. | 1800's-Pres. | Continuous | National Oceanic and Atmospheric Admin. | |
| NRC | The National Referral Center file is non-bibliographic file containing description of organizations qualified and willing to answer questions on virtually any area of science and technology, including the social sciences. | Current | | National Referral Center for Science & Technology | Citations only |
| NSA | Nuclear Science Abstracts - Subject scope includes all of nuclear science and technology. | 1967-1976 | 554,597 records; closed | DOE-TIC | Abstracts |
| NSC | Covers all pertinent literature on nuclear safety information. | 1963-Pres. | 101,340 items; 1,000 citations per month | Nuclear Safety Information Center, Oak Ridge National Laboratory | Abstracts |

SELECTED DATA BASES FOR GROUND WATER INVESTIGATIONS (Cont.)

| Data Base Name | Subject Coverage | Coverage Dates | Update Frequency | Sponsoring Agency | Comments |
|---|---|---|---|---|---|
| NSR | The Nuclear Structure Reference data base contains: 1. The entire contents of "Nuclear Structure References, 1969-1974," supplement to Vol. 16, Nuclear Data Sheets. 2. Complete contents of the 1975 "Recent References" issues of Nuclear Data Sheets; and 3. References to reports and informal communications (secondary sources) received by the nuclear data project during the years 1973-1975. | 1974-Pres. 5,000 entries | 30,236 items; 5,000 entries per year | Oak Ridge National Laboratory | Citations only |
| NTIS | Complete government reports announcement file. Contains abstracts of research reports from over 240 governments agencies including NASA, EPA, HEW, etc. | 1964-Pres. | 765,000 citations; biweekly updates | National Technical Information Service | Abstracts |
| OHM-TADS | Oil and Hazardous Materials-Technical Assistance Data System contains data on materials that have been designated oil or hazardous materials. The system is designed to provide technical support for dealing with potential or actual dangers resulting from the discharge of oil or hazardous substances. | Oct. 1978-Pres. | | EPA-Oil & Special Materials Control Division | |
| PARCS | Pesticides Analysis Retrieval and Control Systems (PARCS) provides a centralized source of information on all pesticides registered by EPA. | | | EPA | |
| POLLUTION ABSTRACTS | Corresponds in coverage to the printed abstracts publication. Covers foreign and domestic reports, journals, contracts and patents, symposia, and government documents in the areas of pollutions control and research; water, marine, land and thermal pollution; pesticides; sewage and waste treatments; and legal developments. | 1970-Pres. | 68,500 citations; bimonthly updates | Data Courier, Inc. | Citations only |

SELECTED DATA BASES FOR GROUND WATER INVESTIGATIONS (Cont.)

| Data Base Name | Subject Coverage | Coverage Dates | Update Frequency | Sponsoring Agency | Comments |
|---|---|---|---|---|---|
| RASS | Rock analysis Storage System - Contains information on samples submitted for analytical work. Information includes location, formation, sample name, age, descriptions, economic geology, data, and geochemical data. | 1962-Pres. 1968-Pres. (2 files) | As necessary 135,000 records 292,000 records | U.S. Geological | |
| RING DOC | RINGDOC covers over 400 of the world's scientific journals to provide extensive coverage of the pharmaceutical literature. Access points to the citations include keywords and multipunch coded data (representing chemical fragments). | 1964-Pres. | 466,000 items 10,000 items/ month | Derwent Publications, Ltd. | Available to subscribers only |
| RTECS | Registry of Toxic Effects of Chemical Substances. | 1978 | 40,967 records | NIOSH | |
| SAFETY | Safety provides international coverage of the literature in 6 major areas: general safety, industrial and occupational safety, transportation safety, aviation and aerospace safety, and medical safety. | June 1975-Pres. | Updated bi-monthly | Cambridge Scientific Abstracts, Riverdale, MD | Abstracts |
| SCISEARCH | Multidisciplinary index to the literature of science and technology. Based on Science Citation Index which indexes approximately 2,600 major scientific and technical journals. | 1974-Pres. | 2,970,000 citations; monthly updates | Institute for Scientific Information | Citations only |
| STORET | Storage and retrieval of water quality data - repository for water quality data that contains records of water quality parametric data by sampling site. | 1976-Pres. | Bi-monthly | Paint Research | Abstract |
| TOXICOLOGY DATA BANK (TDB) | Contains facts and data from some 80 standard references textbooks, handbooks, monographs, and criteria documents, for approximately 2500 substances; 1100 of these have been completed; 1500 are in process. TDB contains approximate 60 different categories of data, such as chemical, physical, biological, pharmacological, toxicological, and environmental facts. | 1978-Pres. | 2500 Substances | National Library of Medicine | |

SELECTED DATA BASES FOR GROUND WATER INVESTIGATIONS (Cont.)

| Data Base Name | Subject Coverage | Coverage Dates | Update Frequency | Sponsoring Agency | Comments |
|---|---|---|---|---|---|
| TOXLINE | Contains data on toxicity and adverse effects of environmental pollutants and chemicals on the human food chain, laboratory animals, and biological systems; and analysis techniques in the following subfiles:<br>CBAC - 1965-76 - Chemical abstracts, biochemistry sections.<br>EMIC - 1971-74 - Environmental Mutagen Information Center.<br>HAYES - 1970 - EPA Pesticide File.<br>HEEP - 1971-76 - Health Effects of Environmental Pollutants<br>IPA - 1970-76 - International Pharmaceutical Abstracts<br>PESTAB - (Formally HAPAB) - 1966-76 - Pesticide<br>Abstracts, EPA<br>TERA - 1971-1974 - Teratology<br>TMIC - 1971 - Toxic Materials Information Center<br>TOXBIB - 1968-76 - Index Medicus Toxicity Subset | Varies with subject file | Varies with subject file. 479,926 records | National Library of Medicine | Citations; (Abstracts available) |
| WATSTORE | Water Data Storage and Retreival System - Contains data on the occurrence, quantity quality, distribution, and movement of surface and underground waters. | Historical-Pres. | As necessary Includes data on over 100,000 sites | U.S. Geological Survey | |

SELECTED DATA BASES FOR GROUND WATER INVESTIGATIONS (Cont.)

| Data Base Name | Subject Coverage | Coverage Dates | Update Frequency | Sponsoring Agency | Comments |
|---|---|---|---|---|---|
| WESTLAW | Contains Supreme Court full text and headnote summaries from 1932 - present; headnote summaries for all reported Federal court cases from 1960 - present; and all reported State Appellate Court cases from 1967 - present. Full test accessible for all Federal court cases from 1977 - present. The subfiles correspond to the units of the West Company National Reporter System. | 1932-pres. | Number of items varies with subject files | West Publishing Company | |
| WRA | Corresponds to the semi-monthly abstracting journal, Selected Water Resources Abstracts. Covers the water-related aspects of the life, physical, and social sciences as well as related engineering and legal aspects of the characteristics, conservation, control, use or management of water. Input material for the abstracts comes from selected organizations with active water resources research programs which are supported as "Centers of Competence." | 1969-Pres. | 94,610 items 1,000 items/mon. | Water Resources Scientific Information Center | Abstracts |

# STATE GEOLOGICAL SURVEYS

<u>Arizona</u>
Arizona Bureau of Geology and
Mineral Technology
845 N. Park Avenue
Tucson, AZ 85719
602-626-2733

<u>California</u>
California Division of Mines and Geology
Department of Conservation
1416 Ninth St.
Sacramento, CA 95814
916-445-1923

<u>Colorado</u>
Colorado Geological Survey
Department of Natural Resources
1313 Sherman Street, Room 715
Denver, CO 80203
303-866-2611

<u>Idaho</u>
Idaho Bureau of Mines and Geology
Moscow, ID 83843
208-885-6785

<u>Montana</u>
Montana Bureau of Mines and Geology
c/o Montana College of
Mineral Science and Technology
Butte, MT 59701
406-496-4166

<u>Nevada</u>
Nevada Bureau of Mines and Geology
University of Nevada
Reno, NV 89557
702-784-6691

<u>New Mexico</u>
New Mexico Bureau of Mines and
Campus Station
Socorro, NM 87801
505-835-5302

<u>North Dakota</u>
North Dakota Geological Survey
University Station
Grand Forks, North Dakota 58202

<u>Oregon</u>
Oregon Department of Geology
and Mineral Industries
1068 State Office Building
Portland, OR 97201
503-229-5580

<u>Utah</u>
Utah Geological and Mineral
Survey
Department of Natural Resources
606 Black Hawk Way
Salt Lake City, UT 84108
801-581-6831

<u>Washington</u>
Washington Division of Geology
and Earth Resources
Department of Natural Resources
Public Lands Bldg.
Olympia, WA 89504
206-459-6372

<u>Wyoming</u>
Geological Survey of Wyoming
Box 3008
University Station
Laramie, WY 82071
307-742-2054

STATE AGENCY CONTACTS FOR GROUND-WATER MANAGEMENT AND PROTECTION

| | Management | Protection |
|---|---|---|
| Arizona | Arizona Dept. of Water Resources<br>999 E. Virginia Ave.<br>Phoenix, AZ 85004<br>(602)255-1586<br>Several divisions handle water matters. These are:<br>Planning and Compliance<br>Technical Support<br>Basic Data<br>Hydrology | State Dept. of Health<br>Office of Waste & Water Quality<br>2005 N. Central<br>Phoenix, AZ 85004<br>(602)257-2704<br>Also includes the Office of Emergency Response and Environmental Analysis |
| California | California Dept. of Water Resources<br>P. O. Box 388<br>Sacramento, CA 95802<br>916-445-2182 | California Water Resources Control Board<br>P. O. Box 100<br>Sacramento, CA 95801<br>916-322-8353 |
| Colorado | Water Quality Control Division<br>Colorado Department of Health<br>4210 E. 11th Avenue<br>Denver, CO 80220<br>303-320-4163 | Water Quality Control Division<br>Colorado Department of Health<br>4210 E. 11th Avenue<br>Denver, CO 80220<br>303-320-4163 |
| Idaho | Idaho Dept. of Water Resources<br>Statehouse<br>Boise, ID 83720<br>208-334-4440 | Water Quality Bureau<br>Dept. of Health & Welfare<br>Statehouse<br>Boise, ID 83720<br>208-334-4255 |
| Montana | Montana Dept. of Natural Resources<br>32 South Ewing<br>Helena, MT 59620<br>409-449-3962 | Montana Department of Health and Environmental Sciences<br>Water Quality Bureau<br>Capitol Station<br>Helena, MT 59620<br>406-449-2406 |

| | Management | Protection |
|---|---|---|
| Nevada | State Engineer<br>Dept. of Conservation and<br>Nat. Resources<br>201 So. Fall Street<br>Carson City, NV 89710 | Nevada Dept. of Natural Resources<br>Div. of Environmental Protection<br>Water Quality Section<br>201 Fall Street<br>Carson City, NV 89710 |
| New Mexico | State Engineer's Office<br>Natural Resources Dept.<br>Bataan Memorial Building<br>Santa Fe, NM 87503 | Water Pollution Control Bureau<br>Ground-Water Section<br>P. O. Box 968<br>Santa Fe, MN 87503 |
| Oregon | Oregon Dept. of Water Resources<br>Ground-Water Section<br>555 13th Street, N.E.<br>Salem, OR 97310 | Oregon Dept. of Environmental<br>Quality.<br>Water Quality Division<br>P. O. Box 1760<br>Portland, OR 97207 |
| Utah | Utah Division of Water Rights<br>Dept. of Natural Resources<br>1636 W. North Temple<br>Salt Lake City, UT 84116<br>801-53f3-6071 | Bureau of Water Pollution<br>Div. of Environmental Health<br>Utah Department of Health<br>150 W. North Temple, Room 426<br>Salt Lake City, UT 84110<br>801-533-6146 |
| Washington | Water Quality Planning and<br>Management Section<br>Department of Ecology<br>M/S PV-11<br>Olympia, WA 98504<br>206-459-6074 | Water Quality Planning and<br>Management Section<br>Department of Ecology<br>M/S PV-11<br>Olympia, WA 98504<br>206-459-6074 |
| Wyoming | Wyoming State Engineer's Office<br>Barrett Building<br>Cheyenne, Wyoming 82002 | Wyoming Dept. of Environ. Quality<br>Solid/Hazardous Waste Management<br>401 West 19th St.<br>Cheyenne, WY 82002<br><br>Wyoming Dept. of Environ. Quality<br>Water Quality Divison<br>1111 E. Lincoln Way<br>Cheyenne, WY 82002 |

## COMPUTER-BASED STATE AND SUB-STATE DATA BASES

| STATE - DATA BASE NAME | AGENCY |
|---|---|
| **Arizona** | |
| Digital Topo Data base | Arizona State Land Department |
| **California** | |
| Land use | Department of Water Resources |
| Division of Land Resources Protection-Soils Program | Department of Conservation |
| **Colorado** | |
| Colorado Resource Information System | Department of Natural Resources |
| **Idaho** | |
| Land Information and Mapping System | Department of Lands |
| Idaho Water Rights | Department of Water Resources |
| Idaho Water Use Data System | Department of Water Resources |
| **Montana** | |
| Montana Water Quality Records System | Department of Health Water Quality Bureau |
| Stream Flows<br>Well and Spring Locations | Department of Natural Resources and Conservation<br>Water Rights Bureau<br>Helena, Montana 59620 |
| **Nevada** | |
| Ground Water | Department of Data Processing |
| Surface Water | Department of Data Processing |
| **New Mexico** | |
| New Mexico Natural Resources Information System | Natural Resources Department |
| Water Use Data | State Engineer Office |

Appendix G, page 2

| | |
|---|---|
| North Dakota | |
| Annual Use Reports on Water Permits | State Water Commission |
| Abandoned Mine Lands | Public Service Commission |
| Oregon | |
| Minerals Registry | State Land Division |
| Ground-Water Sources and Aquifer Data observation well net | Water Resources Department |
| Water Quality (WATSTORE & STORET) | Water Resources Department |
| Streamflow Records | Water Resources Department |
| Water Rights | Water Resources Department |
| Utah | |
| UGMS CRIB File | Utah Geological and Mineral Survey |
| Washington | |
| Water Quality Classifications Monitoring Stations and Non-Changing Data | Department of Ecology |
| AIMS (Surface Mining Permits) | Department of Natural Resources |
| GRIDS - Gridded Resource Inventory Data System | Department of Natural Resources |
| Wyoming | |
| Wyoming Water Resource Data System | Wyoming Water Resources Center |

1. SOURCES OF AVAILABLE PHOTOGRAPHS

Information on and sources of aerial photographs and other imagery include:

1. U.S. Dept. of Agriculture
   Agricultural Research and Conservation Service
   Aerial Photography Field Office
   2222 West 2300 South
   P.O. Box 30010
   Salt Lake City, Utah 84125

   Most photos are at the following scales: (although other scales are available up to 1:80,000)
   1:15,840 or 1 inch = 1320 ft.
   1:20,000 or 1 inch = 1667 ft.
   1:40,000 or 1 inch = 3333 ft.

2. Rocky Mountain National Cartographic Information Center (NCIC)
   U.S. Geological Survey
   Building 25, Denver Federal Center, Room H-2206
   Denver, Colorado 80225
   (FTS) 234-2326

3. Environmental Photographic Interpretation Center (EPIC)
   P.O. Box 1587
   Vint Hill Farm Station
   Warrenton, Virginia 22186
   (FTS) 557-3110

4. Environmental Monitoring Systems Laboratory (EMSL)
   P.O. Box 15027
   Las Vegas, Nevada 89114
   (FTS) 595-2969

5. EROS Data Center
   Souix Falls, South Dakota 57198
   FTS 784-7114

6. BLM photography includes low level aerial photography plus some high altitude photos from the EROS Data Center, Sioux Falls, SD. Information is available from:

   U.S. Dept. of Interior
   Bureau of Land Management
   Denver Service Center
   Denver Federal Center, Bldg. 50
   Lakewood, CO 80225

EMSL is capable of flying both simple and sophisticated remote sensing missions. Their equipment ranges from mapping quality black and white or color cameras to multispectral scanners with a variety of airborne sensor platforms. Generally, they can provide full remote sensing services to governmental organizations.

## REGIONAL QUALITY-ASSURANCE COORDINATORS

The following offices can provide you with the names and locations of state or EPA certified laboratories in your state. Ask the Quality Assurance Officer or the Environmental Sources Division Director.

Region 1 (Maine, Vermont, New Hampshire, Massachusetts, Connecticut, Rhode Island)

Quality Assurance Officer
Central Regional Laboratory
Environmental Services Division
U.S. Environmental Protection Agency
60 Westview Street
Lexington, Massachusetts 02173

Region 2 (New York, New Jersey)

Quality Assurance Officer
Environmental Services Division
U.S. Environmental Protection Agency
Edison, New Jersey 08837

Region 3 (Pennsylvania, Virginia, West Virginia)

Quality Assurance Officer
Water Quality Monitoring Branch
U.S. Environmental Protection Agency
Sixth and Walnut Streets, Curtis Building
Philadelphia, Pennsylvania 19106

Region 4 (Kentucky, North Carolina, Tennessee, Mississippi, Alabama, Georgia, South Carolina, Florida)

Quality Assurance Officer
Laboratory Services Branch
Environmental Services Division
U.S. Environmental Protection Agency
College Station Road
Athens, Georgia 30613

Region 5 (Wisconsin, Illinois, Indiana, Ohio, Michigan)

Quality Assurance Officer
Environmental Services Division
U.S. Environmental Protection Agency
536 South Clark Street
Chicago, Illinois 60605

Region 6 (New Mexico, Texas, Oklahoma, Arkansas, Louisiana)

Quality Assurance Officer
Environmental Services Division
U.S. Environmental Protection Agency
1201 Elm Street
First International Building
Dallas, Texas 75270

Region 7 (Nebraska, Iowa, Missouri, Kansas)

Quality Assurance Officer/Chief
Laboratory Branch
Environmental Services Division
U.S. Environmental Protection Agency
25 Funston Road
Kansas City, Kansas 66115

Region 8 (Montana, North Dakota, South Dakota, Wyoming, Colorado, Utah)

Quality Assurance Officer
Environmental Services Division
U.S. Environmental Protection Agency
Lincoln Tower Building, Suite 900
1860 Lincoln Street
Denver, Colorado 80295

Region 9 (California, Nevada, Arizona)

Quality Assurance Officer
Office of Quality Assurance and Monitoring Systems
U.S. Environmental Protection Agency
215 Fremont Street
San Francisco, California 94105

Region 10 (Washington, Oregon, Idaho)

Quality Assurance Officer
Environmental Services Division
U.S. Environmental Protection Agency
1200 Sixth Avenue, Mail Stop 345
Seattle, Washington 9810

## IV. HP-85 MICROCOMPUTER ANALYTICAL GROUND-WATER MODELS

(Available from the Division of Resource Systems, Denver Service Center.)

Program 1. General Aquifer Analysis for Nonsteady Theis Conditions - Calculates drawdown at given observation points due to an array of point wells with known pump/recharge rates.

Program 2. Alluvial Valley Floor Analysis - Calculates drawdown at given observation points due to a single well bounded by parallel impermeable or constant head valley walls.

Program 3. Analysis of Source or Sink Flow Rates with Drawdown as Given - Calculates pump rate for an array of wells given a fixed-time drawdown for each well.

Program 4. Steady-state Drawdown Around Finite Line Sinks - Calculates the drawdown at given observation points due to an array of finite line sinks assuming steady-state conditions.

Program 5. Finite Line Sinks for Nonsteady Conditions - Calculates the drawdown at a given observation point from an array of line sinks by integrating the Theis expression for a point along each line with given pump/recharge.

Program 6. Study of Steady-state Flow to Finite Line Sources or Sinks with Drawdown as the Given - Calculates the pumping/recharge rates from an array of lines with a given set of drawdown assuming steady-state conditions.

Program 7. Analysis of Ground Water Mounding Beneath Tailing Ponds - Calculates augmented head above undisturbed water level for a circular tailing pond as a function of time.

Program 8. Mass Transport of Pollutant from a River to a Well - Calculates the concentration as a function of time of pollutant from a river adjacent to a single well.

Program 9. Plume Management Model - Calculates the concentration at a given observation point due to injection of pollutant at a given point as a result of dispersivity/ground-water flow.

Contact the Ground Water Coordinator, Denver Service Center, D-470

# SUBSURFACE-WATER FLOW AND SOLUTE TRANSPORT--

# GLOSSARY OF SELECTED TERMS

Prepared by the
Subsurface-Water Glossary Working Group
Ground-Water Subcommittee
Interagency Advisory Committee on Water Data

October 1985

**DRAFT**

## FOREWORD

The purpose of this document is to present a glossary of selected terms for saturated and unsaturated flow and related processes involved in transport of contaminants in the subsurface. Included with the glossary is a table of parameters, their symbols, and units of measure. It is hoped that this glossary will aid in the interactive communications of soil scientists, hydrologists, hydrogeologists, and geologists.

The terms defined in the glossary were selected after an extensive survey of glossaries in the areas of (1) ground-water geology, hydraulics, and chemistry, (2) soil-water physics and chemistry, (3) contaminant transport, (4) unsaturated zone hydrology, (5) chemistry and transport of solutes, and (6) ground-water quality. The original manuscript was prepared by Thomas J. Nicholson, U.S. Nuclear Regulatory Commission. Subsequently, it was examined by the Ground-Water Glossary Working Group and several dozen experts within and outside the Federal Government, whose recommendations were accommodated where appropriate in this present draft.

This glossary is a compilation of definitions, some of which have been modified for clarity, from a variety of technical sources. Where more then one definition appears for the selected term, the first one was determined by the working group to be the most appropriate general definition, followed by other more specialized definitions. The reader is encouraged to consult with the original source cited for more explanatory comments.

The principal sources for the definitions are from a recent compilation by A. I. Johnson entitled. "Glossary." in <u>Permeability and Groundwater Contaminant Transport</u>, ASTM STP 746, T. F. Zimmie and C. O. Riggs, Eds., American Society for Testing and Materials, 1981. pp. 3-17, and Manual 40, "Ground-water Management...American Society of Civil Engineers" 1985. This draft glossary will be forwarded to the Federal members of the Interagency Advisory Committee on Water Data (IACWD), and non-Federal members of the Advisory Committee on Water Data for Public Use (ACWOPU) for their review.

It is anticipated that the glossary will be updated on a periodic basis.

DRAFT

absorption - the process by which substances in gaseous, liquids or solid form dissolve or mix with other substances (ASCE, 1985).

adsorption - adherence of gas molecules, ions, or molecules in solution to the surface of solids (ASCE, 1985).

advection - the process whereby solutes are transported by the bulk mass of flowing fluid (Freeze, 1979) (see also convective transport).

air-space ratio, (D)* - the ratio of (a) the volume of water that can be drained from a saturated soil or rock under the action of force of gravity to (b) the total volume of voids (ASTM, 1980).

anisotropy - the condition of having different properties in different directions (AGI, 1980).

anisotropic mass - a mass having different properties in different directions at any given point (ASTM, 1980).

apparent ground-water velocity - see specific discharge.

aquiclude - a formation which, although porous and capable of storing water, does not transmit it at rates sufficient to furnish an appreciable supply for a well or spring (after WMO, 1974) (see also confining unit).

aquifer - a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs (after Lohman and others, 1972).

aquifer system - a body of permeable and poorly permeable material that functions regionally as a water yielding unit; it comprises two or more permeable beds separated at least locally by confining beds that impede continuity of the system; includes both saturated and unsaturated parts of permeable material (after ASCE, 1985).

aquifer test - a test to determine hydrologic properties of the aquifer involving the withdrawal of measured quantities of water from or addition of water to a well and the measurement of resulting changes in head in the aquifer both during and after the period of discharge or additions (ASCE, 1985).

aquifuge -

(1) a formation which has no interconnected openings and hence cannot store or transmit water (after WMO, 1974).

(2) a rock which contains no interconnected openings or interstices and therefore neither stores nor transmits water;

(3) an impermeable rock (ASCE, 1985). (see also confining unit).

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*The abbreviations in parantheses stand for terms of measurement and are defined as follows: D = dimensionless; L = length; T = time; and M = mass



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aquitard - a confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. It does not readily yield water to wells or springs, but may serve as a storage unit for ground water (AGI, 1980) (see also confining unit).

area of influence of a well - the area surrounding a pumping or recharging well within which the potentiometric surface has been changed (after ASCE, 1985).

artesian - synonymous with confined (Lohman and others, 1972).

artesian aquifer - synonymous with confined aquifer (ASCE, 1985).

artesian well - a well deriving its water from an artesian or confined aquifer (after ASCE, 1985).

artificial recharge - recharge at a rate greater than natural, resulting from deliberate or incidental human activities (WRC, 1980).

average interstitial velocity - see velocity, average interstitial.

base flow - that part of the stream discharge that is not attributable to direct runoff from precipitation or melting snow, it is usually sustained by ground-water discharge (after APHA, 1981).

baseline monitoring - the establishment and operation of a designed surveillance system for continuous or periodic measurements and recording of existing and changing conditions that will be compared with future observations (after NRC, 1982).

breakthrough curve - a plot of relative concentration versus time where relative concentration is defined as C/Co with C as the concentration at a point in the ground-water flow domain, and Co as the source concentration.

buildup, (L) - the vertical distance the water elevation is raised, or the increase of the pressure head due to the addition of water.

capillary action - the movement of water in the interstices of a porous medium due to capillary forces (synonymous with capillarity, capillary flow, and capillary migration) (after ASTM, 1980).

capillary conductivity -

(1) the property of an unsaturated porous medium to transmit liquid (after AGI, 1980).

(2) coefficient which expresses the extent to which an unsaturated permeable medium allows flow of water through its interstices, under a unit gradient of capillary potential (after WMO, 1974).

DRAFT

capillary fringe - the lower subdivision of the unsaturated zone immediately above the water table in which the interstices are filled with water under pressure less than that of the atmosphere, being continuous with the water below the water table but held above it by capillary forces (after ASCE, 1985).

capillary head, (L) - the potential, expressed in head of water, that causes the water to flow by capillary action (ASTM, 1980).

capillary migration - see capillary action.

capillary potential, ($ML^{-1} T^{-1}$) - the scalar quantity that represents the work required to move a unit mass of water from the soil to a chosen reference location and energy state (after SSSA, 1975).

capillary pressure, ($ML^{-1} T^{-2}$) - the difference in pressure across the interface between two immiscible fluid phases jointly occupying the interstices of a porous medium caused by interfacial tensions between the two phases (after AGI, 1980).

capillary rise (height of capillary rise), (L) - the height above a free water surface to which water will rise by capillary action (synonymous with height of capillary rise) (ASTM, 1980).

capillary water -

(1) water held in the soil above the phreatic surface by capillary forces;

(2) soil water above hydroscopic moisture and below the field capacity (WMO, 1974).

cascading water - in reference to wells, ground water which trickles or pours down the casing or uncased borehole above the water level in the well through cracks or perforations.

cation exchange capacity (meq $M^{-1}$) - the sum total of exchangeable cations that a porous medium can absorb. Expressed in milliequivalents per 100 grams or per gram of soil (or of other exchanges such as clay) (SSSA, 1975).

centrifuge moisture equivalent - see moisture equivalent.

cone of depression - a depression of the potetionmetric surface in the shape of an inverted cone that develops around a well which is being pumped (after ASCE, 1985).

cone of impression - a rise of the potentiometric surface in the shape of a cone that develops around an injection well.

confined - a modifier which describes a condition in which the potentiometric surface is above the top of the aquifer: synonymous with artesian.

confined aquifer -

(1) an aquifer bounded above and below by confining units of distinctly lower permeability than that of the aquifer itself;

(2) an aquifer containing confined ground water (ASCE, 1985).

DRAFT

confining unit - a hydrogeologic unit of impermeable or distinctly less permeable material bounding one or more aquifers and is a general term that replaces aquitard, aquifuge, aquiclude (synonymous with confining bed) (after AGI, 1980).

connate water - water entrapped in the interstices of a sedimentary or extrusive igneous rock at the time of its deposition (AGI, 1980).

contaminant - an undesirable substance not normally present or an unusually high concentration of a naturally occurring substance in water or soil.

convective transport - the component of movement of heat or mass induced by thermal gradients in ground water (see also advection).

Oarcian velocity - see specific discharge.

Darcy's law - an empirical law which states that the velocity of flow through a porous medium is directly proportional to the hydraulic gradient assuming that the flow is laminar and inertia can be neglected (after Darcy, 1856).

deep percolation - the drainage of soil water downward by gravity below the maximum effective depth of the root zone toward storage in subsurface strata (ASCE, 1985).

degree of saturation - see percent saturation.

desorption - the reverse process of sorption (see also sorption).

discharge area - an area in which ground water is discharged to the land surface, surface water, or atmosphere (WRC, 1980).

differential water capacity - the absolute value of the rate of change of water content with soil water pressure. The water capacity at a given water content will depend on the particular desorption or adsorption curve employed. Distinction should be made between volumetric and specific water capacity (SSSA, 1975).

diffusion coefficient - see molecular diffusion coefficient.

diffusivity, soil water, ($L^2$ $T^{-1}$) - the hydraulic conductivity divided by the differential water capacity (care being taken to be consistent with units), or the flux of water per unit gradient of moisture content in the absence of other force fields (SSSA, 1975).

diffusivity, hydraulic ($L^2$ $T^{-1}$) - the ratio of transmissivity divided by the storage coefficient or the hydraulic conductivity divided by the specific storage (Lohman and others, 1972).

dispersion coefficient ($L^2$ $T^{-1}$) -

(I) a measure of the spreading of a flowing substance due to the nature of the porous medium with its interconnected channels distributed at random in all directions (ANS, 1970).

(2) the sum of the coefficients of mechanical dispersion and molecular diffusion in a porous medium (Bear, 1979).

dispersivity, (L) - a geometric property of a porous medium which determines the dispersion characteristics of the medium by relating the components of pore velocity to the dispersion coefficient (ANS, 1980).

distribution coefficient, ($L^3\ M^{-1}$) - the quantity of the solute, chemical or radionuclide sorbed by the solid per unit weight of solid divided by the quantity dissolved in the water per unit volume of water (ANS, 1980).

drainage well -

(1) a well installed to drain surface water, storm water, or treated waste water into underground strata;

(2) a water well constructed to remove subsurface water or to reduce potentiometric levels (after ASCE, 1985).

drawdown (L) -

(1) the vertical distance the water elevation is lowered or the reduction of the pressure head due to the removal of water (after ASCE, 1985).

(2) the decline in potentiometric surface at a point caused by the withdrawal of water from a hydrogeologic unit (after Heath, 1983).

effective hydraulic conductivity - see hydraulic conductivity, effective.

effective porosity (D) - see porosity, effective.

effluent stream - see gaining stream.

electrical conductivity - the measure of the ability of material to conduct an electrical current. For water samples, its magnitude depends on the concentration of dissolved constituents in the water related to total dissolved solids (after ASCE, 1985).

equipotential line (or surface) - line (or surface) along which the potential is constant (WMO, 1974).

evapotranspiration - the combined loss of water from a given area and during a specified period of time, by evaporation from the land and transpiration from plants (SSSA, 1975).

exchange capacity, (meq $M^{-1}$) -

(1) the amount of exchangeable ions measured in milliequivalents per 100 grams of solid material at a given pH (synonymous with ion exchange capacity) (ANS, 1980).

(2) the total ionic charge of the adsorption complex active in the adsorption of ions (SSSA, 1975) (see also cation-exchange capacity).

field capacity (field moisture capacity) - see specific retention.

flow line - the general path that a particle of water follows under laminar flow conditions (after ASTM. 1980).

flow net - a graphical representation of flow lines and equipotential lines for two-dimensional, steady-state ground-water flow (after ASTM, 1980).

flow path - the subsurface course a water molecule or solute would follow in a given ground-water velocity field.

flow steady - a characteristic of a flow system where the magnitude and direction of specific discharge are constant in time at any point (see also flow, unsteady).

flow uniform - a characteristic of a flow system where specific discharge has the same magnitude and direction at any point.

flow nonsteady - a characteristic of a flow system where the magnitude and/or direction of the specific discharge changes with time (synonymous with unsteady flow) (see also flow, steady).

flow velocity - see specific discharge.

fluid potential, ($L^2$ $T^{-2}$) - the mechanical energy per unit mass of a fluid at any given point in space and time with regard to an arbitrary state and datum (Lohman and others, 1972).

flux - see specific discharge.

free water - see gravitational water

free water elevation - see water table.

gaining stream - a stream or reach of a stream whose flow is being increased by inflow of ground water (ASCE, 1985).

gravitational head, (L) - the component of total hydraulic head related to the position of a given mass of water relative to an arbitrary datum (Wilson, 1980).

gravitational water - water which moves into. through, or out of the soil or rock mass under the influence of gravity (SSSA, 1975).

ground water -

(1) that part of the subsurface water that is in the saturated zone.

(2) loosely, all subsurface water as distinct from surface water (ASCE, 1985).

(3) all water which occurs below the land surface. It includes both water within the unsaturated and saturated zones (NRC, 1985).

ground-water barrier - rock or artificial material which has a relatively low permeability and which occurs below the land surface where it impedes the movement of ground water and consequently causes a pronounced difference in the potentiometric level on opposite sides of it (after ASCE, 1985).

ground-water basin - a general term used to define a ground-water flow system that has defined boundaries and may include more than one aquifer underlain by permeable materials which are capable of storing or furnishing a significant water supply; the basin includes both the surface area and the permeable materials beneath it (ASCE, 1985).

ground-water, confined - ground water under pressure significantly greater than atmospheric whose potentiometric surface is above the top of the aquifer (after Lohman, 1972) (see also confined, confining unit, and confined aquifer).

ground-water discharge ($L^3 T^{-1}$) -

(1) flow of water from the zone of saturation;

(2) the water released from the zone of saturation;

(3) the quantity of water released (ASCE, 1985).

ground-water divide - a ridge in the water table or other potentiometric surface from which ground water moves away in both directions normal to the ridge line (WRC, 1980).

ground-water flow - the movement of water in the zone of saturation.

ground-water mound - a raised area in a water table or other potentiometric surface created by ground-water recharge.

ground water, perched - see perched ground water.

ground-water recharge - the process of water addition to the saturated zone or the volume of water added by this process (ANS, 1980).

ground water, unconfined - water in an aquifer that has a water table (synonymous with phreatic ground water) (Lohman and others, 1972).

head, static, (L) - the height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point. The static head is the sum of the elevation head and the pressure head (after Lohman and others, 1972).

head total, (L) - the total head of a liquid at a given point is the sum of three components: (a) the elevation head, which is equal to the elevation of the point above a datum, (b) the pressure head, which is the height of a column of static water that can be supported by the static pressure at the point, and (c) the velocity head, which is the height to which the kinetic energy of the liquid is capable of lifting the liquid (Lohman and others, 1972).

heterogeneity - a characteristic of a medium in which material properties vary from point to point (after ANS, 1980).

homogeneity - a characteristic of a medium in which material properties are identical everywhere (see Lohman and others, 1972).

hydraulic barrier - a general term referring to modifications of a ground-water flow system to restrict or impede movement of contaminants.

hydraulic conductivity, ($L\ T^{-1}$) - a proportionality constant relating hydraulic gradient to specific discharge which for an isotropic medium and homogeneous fluid equals the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow (after ASCE, 1985).

hydraulic conductivity, effective, ($L\ T^{-1}$) - the rate of flow of water through a porous medium that contains more than one fluid such as water and air in the unsaturated zone, and which should be specified in terms of both the fluid type and content and the existing pressure (Lohman and others, 1972).

hydraulic diffusivity, ($L^2\ T^{-1}$) - see diffusivity, hydraulic.

hydraulic gradient, (D) -

(1) the change in static head per unit of distance in a given direction. If not specified. the direction generally is understood to be that of the maximum rate of decrease in head;

(2) scope of the water table or potentiometric surface (ASCE, 1985).

hydraulic head, (L) - the height above a datum plane (such as sea level) of the column of water that can be supported by the hydraulic pressure at a given point in a ground water system. For a well, the hydraulic head is equal to the distance between the water level in the well and the datum plane (ASCE, 1985).

hydrochemical facies - the diagnostic chemical character of water solutions in hy drologic systems (Back, 1966).

hydrodynamic dispersion - the spreading (at the macroscopic level) of the solute front during transport resulting from both mechanical dispersion and molecular diffusion (Bear, 1979).

hydrodynamic dispersion, coefficient of - see dispersion coefficient.

hydrogeologic unit - any soil or rock unit or zone which by virtue of its hydraulic properties has a distinct influence on the storage or movement of ground water (after ANS, 1980).

hydrograph - a graph relating stage, flow, velocity, or other characteristics of water with respect to time (after ASCE, 1985).

hydrostatic pressure - the pressure exerted by the weight of water at any given point in a body of water at rest (after AGI, 1972).



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hydrostratigraphic unit - see hydrogeologic unit.

immiscible -

(1) two or more liquids that are not readily soluable;

(2) the chemical property of two or more phases that, at mutual equilibrium, cannot dissolve completely in one another, e.g. oil and water (AGI, 1980).

impermeable - a characteristic of some geologic material that limits their ability to transmit significant quantities of water under the pressure differences ordinarily found in the subsurface (after ASCE).

infiltration - the downward entry of water into the soil or rock (SSSA, 1975).

infiltration capacity - the maximum rate at which a soil or rock is capable of absorbing water or limiting infiltration rate (after ASCE, 1985).

infiltration rate, $(LT^{-1})$ -

(1) the rate at which a soil or rock under specified conditions absorbs falling rain, melting snow, or surface water expressed in depth of water per unit time (ASCE, 1985).

(2) a characteristic describing the maximum rate at which water can enter the soil or rock, under specified conditions, including the presence of an excess of water. It has the dimensions of velocity (SSSA, 1975).

influent stream - see losing stream.

injection well - well used for emplacing fluids into the subsurface.

interstice -

(1) an opening in a rock or soil that is not occupied by solid matter. (AGI, 1980).

(2) an opening or space which may be occupied by air, water, or other gaseous or liquid material (synonymous with void, pore) (ASTM, 1980).

intrinsic permeability - see permeability, instrinsic.

in-situ density - the density of water measured at its actual depth (see potential density) (AGI, 1980).

isotropic mass - a mass having the same property of properties of interest are the same in all directions.

laminar flow - flow in which the head loss is proportional to the first power of the velocity (synonymous with streamline flow, viscous flow) (ASTM, 1980).

leachate - materials removed by the process of leaching.

leaching -
(1) the removal of materials in solution from soil, rock, or waste (after SSSA, 1975).

(2) separation or dissolving out of soluble constituents from a porous medium by percolation of water (McGraw-Hill, 1974).

leakage -
(1) the flow of water from one hydrogeologic unit to another. The leakage may be natural, as through semi-impervious confining layer, or man-made, as through an uncased well (APHA, 1981).

(2) the natural loss of water from artificial structures as a result of hydrostatic pressure.

leakance ($T^{-1}$) -
(1) the ratio K'/b', in which K' and b' are the vertical hydraulic conductivity and the thickness, respectively, of the confining beds (Lohman and others, 1972).

(2) the rate of flow across a unit (horizontal) area of a semipervious layer into (or out of) an aquifer under one unit of head difference across this layer (synonymous with coefficient of leakage) (Bear, 1979).

leaky aquifer - aquifers. whether artesian or water-table, that lose or gain water through adjacent semipervious layers (Hantush, 1964).

line of seepage - see seepage line.

losing stream - a stream or reach of a stream in which water flows from the stream bed into the ground (synonymous with influent stream) (ASCE, 1985).

lysimeter - a device for measuring percolation and leaching losses from a column of soil under controlled conditions (SSSA, 1975).

matric potential, (L) - the energy required to extract water from a porous medium to overcome the capillary and adsorptive forces (after Wilson, 1980).

matrix - the solid framework of a porous system (Wilson, 1980).

mechanical dispersion - the process whereby solutes are mechanically mixed during advective transport caused by the velocity variations at the microscopic level (synonymous with hydraulic dispersion).

mechanical dispersion, coefficient ($L^2$ $T^{-1}$)- the component of mass transport flux of solutes caused by velocity variations at the microscopic level (synonymous with convective diffusion) (after Bear, 1979).



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miscible -

(1) two or more liquids that are mutually soluable (i.e. they will dissolve in each other) (McGraw-Hill, 1974).

(2) the chemical property of two or more phases that, when brought together, have the ability to mix and form one phase (after AGI, 1980).

miscible displacement -

(1) the mutual mixing and movement of two fluids that are soluable in each other (synonymous with miscible-phase displacement) (after Freeze and Cherry, 1978).

moisture content (D) - the ratio; expressed as a percentage, of either (a) the weight of water to the weight of solid particles expressed as moisture weight percentage or (b) the volume of water to the volume of solid particles expressed as moisture volume percentage in a given volume of porous medium (ASTM, 1980). (see water content).

moisture equivalent - the percentage of water retained in a soil sample 1 cm thick after it has been saturated and subjected to a centrifugal force 1000 times gravity for 30 min (SSSA, 1975). (Centrifuge moisture equivalent is the water content of a soil after it has been saturated with water and then subjected for 1 hour to a force equal to 1000 times that of gravity (ASTM, 1980).

moisture tension - the equivalent negative pressure of water in an unsaturated porous medium equal to the pressure that must be applied to the medium to bring the water to hydraulic equilibrium through a porous permeable material with a pool of water of the same composition (after SSSA, 1975).

moisture volume percentage - the ratio of the bolume of water in a soil to the total bulk volume of the soil (SSSA, 1975).

moisture weight percentage - the moisture content expressed as a percentage of the oven-dry weight of a soil (SSSA, 1975).

molecular diffusion (diffusion) - the process whereby solutes are transported at the microscopic level due to variations in the solute concentrations within the fluid phases.

molecular diffusion, coefficient of ($L^2$ $T^{-1}$) - the component of mass transport flux of solutes (at the microscopic level) due to variations in solute concentrations within the fluid phases (synonymous with diffusion coefficient), (after Bear, 1979).

non-point source - any source, other than a point source, which discharges pollutants into air or water (APHA, 1981).

particulate transport - the movement of undissolved particles in subsurface water.

peclet number (D) - a relationship between the advective and diffusive components of solute transport expressed as the ratio of the product of the average interstitial velocity, times the characteristic length, divided by the coefficient of molecular diffusion; small values indicate diffusion dominance, large values indicate advection dominance.

percent saturation (D) - the ratio, expressed as a percentage, of (a) the volume of water to (b) the total volume of intergranular space (voids) in a given Percus medium (synonymous with degree of saturation) (ASTM, 1980).

perched ground water - ground water separated from an underlying body of ground water by an unsaturated zone (ASCE, 1985).

pellicular water -

(1) the film of water left around each grain or fracture surface of water-bearing material after gravity;

(2) water of adhesion;

(3) water that can be extracted by root absorption and evaporation but cannot be moved by gravity or by the unbalanced film forces resulting from localized evaporation and transpiration (after APHA, 1981).

percolation -

(1) the downward movement of water through the unsaturated zone;

(2) the downward flow of water in saturated or nearly saturated porous medium at hydraulic gradients of the order of 1.0 or less (after SSSA, 1975).

permeability - the property of a porous medium to transmit fluids under an hydraulic gradient.

permeability coefficient, ($LT^{-1}$) - the rate of flow of water through a unit cross-sectional area under a unit hydraulic gradient at the prevailing temperature (field permeability coefficient) or adjusted to a temperature of 15°C (60°F) (ASCE, 1985).

permeability, effective - the observed permeability of a porous medium to one fluid phase under conditions of physical interaction between this phase and other fluid phases present (AGI, 1980).

permeability, intrinsic, ($L^2$) -

(1) a measure of the relative ease with which a porous medium can transmit a fluid under a potential gradient and is a property of the medium alone (after Lohman and others, 1972).

(2) the property of a porons medium itself that expresses the ease with which gases, liquids, or other substances can pass through it (after SSSA, 1975).



DRAFT

permeability, relative -

(1) the ratio of the effective permeability for a given flow phase to the intrinsic permeability of the porous medium (WMO, 1974).

(2) the ratio of the effective and specific permeabilities (Thrush, 1968).

permeability, specific - the permeability measured when the rock contains only one fluid (Thrush, 1968).

phreatic line - see seepage line.

phreatic surface - see water table.

piezometer - a devise used to measure ground-water potentials at a point in the subsurface.

piezometric surface - see potentiometric surface.

point source - any discernable, confined, or discrete conveyance from which pollutants are or may be discharged, including, but not limited to, any pipe, ditch, channel, tunnel, conduit, or vessel or other floating craft (APHA, 1981).

pore - see interstice.

pore space - the total space not occupied by solid soil or rock particles (SSSA, 1975).

pore velocity - see velocity, average interstitial.

porosity, (D) -

(1) the ratio, usually expressed as a percentage, of the total volume of voids of a given porous medium to the total volume of the porous medium (after ASTM, 1980).

(2) the volume percentage of the total bulk not occupied by solid particles (SSSA, 1975).

porosity, effective, (D) -

(1) the ratio, usually expressed as a percentage of the total volume of voids available for fluid transmission to the total volume of the porous medium.

(2) the ratio of the volume of the voids of a soil or rock mass that can be drained by a gravity to the volume of the mass (ASTM, 1980).

potable water - water that is suitable for human consumption.

potential - any of several different scalar quantities, each of which involves energy as a function of position or of condition; e.g. the fluid potential of ground water (AGI, 1980).

potential density -

(1) the density of a unit of water after it is raised by an adiabatic process to the surface, i.e., determined from in-situ salinity and potential temperature (AGI, 1980).

(2) density that would be reached by a compressible fluid if it were adiabatically compressed or expanded to a standard pressure (McGraw-Hill, 1974).

potential drop, (L) - the difference in total head between two equipotential lines (ASTM, 1980).

potentiometric surface - an imaginary surface representing the static head of ground water and defined by the level to which water will rise in a piezometer (WRC, 1980).

pressure head - hydrostatic pressure expressed as the height of a column of water that the pressure can support, expressed with reference to a specific datum such as land surface or sea level (after ASCE, 1985). (see also head, static)

pressure, static, ($M\ L^{-1}\ T^{-2}$) - the pressure exerted by fluid at rest.

radioisotope - an unstable isotope of an element that decays or disintegrates spontaneously emitting radiation (NRC, 1981).

radionuclide - a radioisotope (NRC, 1981).

recharge area - an area in which water reaches the zone of saturation by surface infiltration (Heath, 1984).

saturated zone -

(1) these parts of the earth's crust in which all voids are filled with water under pressure greater than atmospheric (Lohman and others, 1972).

(2) that part of the earth's crust beneath the regional water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric (NRC, 1985).

seep -

(1) an area, generally small, where water or oil percolates slowly to the land surface (see seepage and spring);

(2) to move slowly through small openings of a porous material (AGI, 1980).

seepage -

(1) the fluid discharged at a seep.

(2) the amount of fluid discharged at a seep.

seepage face - a boundary between the saturated flow field and the atmosphere along which ground water discharges, either by evaporation or movement "downhill" along the land surface or in a well as a thin film in response to the force of gravity (after Franke and others, 1985).



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seepage line -

(1) the uppermost level at which flowing water emerges along a seepage face (AGI, 1980).

(2) the upper free water surface of the zone of seepage (synonymous with line of seepage, phreatic line) (ASTM, 1980).

seepage velocity - see specific discharge.

semiconfined aquifer - see leaky aquifer.

soil bulk density - the mass of dry soil per unit bulk soil (SSSA, 1975).

soil moisture (D) - subsurface liquid water in the unsaturated zone expressed as a fraction of the total porous medium volume occupied by water. It is less than or equal to the porosity, n, (NRC, 1985).

soil water - see soil moisture.

soil-water pressure - the pressure (positive or negative), in relation to the external gas pressure on the soil water, to which a solution identical in composition with the soil water must be subjected in order to be in equilibrium through a porous permeable wall with the soil water (SSSA, 1975).

solute transport - the net flux of solute through a hydrogeologic unit controlled by the flow of subsurface water and transport mechanisms.

sorption -

(1) a general term used to encompass the process of absorption and adsorption.

(2) all processes which remove solutes from the fluid phase and concentrate them on the solid phase of the medium (after ANS 1980).

specific capacity, $(^2\ T^{-1})$ - the rate of discharge of water from the well divided by the drawdown of the water level within the well (Lohman and others, 1972).

specific conductance - a measure of the ability of water to conduct an electrical current expressed in micromhos per centimeter at 25°C (ASCE, 1985).

specific discharge $[LT^{-1}]$ - the rate of discharge of ground water per unit area of a porous medium measured at right angle to the direction of flow (synonymous with specific flux) (Lohman and others, 1972).

specific retention, (D) - the ratio of the volume of water which the porous medium, after being saturated, will retain against the pull of gravity to the volume of the porous medium (Lohman and others, 1972).

specific storage, $(L^{-1})$ - the volume of water released from or taken into storage per unit volume of the porous medium per unit change in head (Lohman and others, 1972).

specific yield, (D) - the ratio of the volume of water which the porous medium after being saturated, will yield by gravity to the volume of the porous medium (Lohman and others, 1972).

spring - a discrete place where ground water flows naturally from a rock or the soil onto the land surface or into a body of surface water (ASCE, 1985). (see seep)

static head - see head, static.

storage coefficient, (D) -

(1) the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head (Lohman and others, 1972).

(2) the volume of water a confined hydrogeologic unit releases from or takes into storage per unit subsurface area of the hydrogeologic unit per unit change in head.

storativity - see storage coefficient.

subsurface water - all water that occurs below the land surface.

suction - see moisture tension.

tensiometer - a device used to measure the moisture tension in the unsaturated zone.

total dissolved solids -

(1) the total concentration of dissolved constituents in solution, usually expressed in milligrams per liter.

(2) the total concentration of dissolved material in water [as] ordinarily determined from the weight of the dry residue remaining after evaporation of the volatile portion of an aliquot of the water sample (Hem, 1970).

total hydraulic head - see head, total.

total soil-water potential - the sum of the energy-related components of a soil-water system; i.e., the sum of the gravitational, matric, and osmotic components (Wilson, 1980).

transient -

(1) varying in time.

(2) a pulse dampered oscillation or other temporary phenomena occurring in a system prior to reaching a steady-state condition (McGraw-Hill, 1974).

transmissibility coefficient - (The use of the term transmissibility has been replaced by transmissivity).

transmissivity, ($L^2$ $T^{-1}$) - the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths (Lohman and others, 1972).

transport - conveyance of solutes and particulates in flow systems. (see also solute transport and particulate transport).

turbulent flow - the flow condition in which inertial forces predominate over viscous forces and in which head loss is not linearly related to velocity.

unconfined - a condition which the upper surface of the zone of saturation forms a water table under atmospheric pressure, (after ASCE, 1985).

unsaturated flow - the movement of water in a porous medium in which the pore spaces are not filled to capacity with water (after SSSA, 1975).

unsaturated zone -

(1) the zone between the land surface and the water table (ASCE, 1985).

(2) the zone between the land surface and the deepest water table which includes the capillary fringe. Generally, water in this zone is under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies the water pressure locally may be greater than atmospheric (Lohman and others, 1972).

(3) the zone between the land surface and the regional water table. Generally, water in this zone is under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies the water pressure locally may be greater than atmospheric (NRC, 1985).

vadose zone - see unsaturated zone.

velocity, average interstitial ($LT^{-1}$) - the average rate of ground-water flow in interstices expressed as the produce of hydraulic conductivity and hydraulic gradient divided by the effective porosity, (synonymous with average linear ground-water velocity or effective velocity) (after Lohman and others, 1972).

void - see interstice.

void ratio, (D) - the ratio of (a) the volume of void space to (b) the volume of solid particles in a given soil mass (ASTM, 1980).

water content - the amount of water lost from the soil after drying it to constant weight at 105$^{o}$C, expressed either as the weight of water per unit weight of dry soil or as the volume of water per unit bulk volume of soil (ASTM, 1980). (see moisture content).

water-holding capacity - see specific retention.

water table -

(1) the upper surface of a zone of saturation except where that surface is formed by a confining unit (after Lohman, 1972).

(2) the upper surface of the zone of saturation on which the water pressure in the porous medium equals atmospheric pressure.



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DRAFT

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DRAFT

Table 1. List of Parameters, Their Symbols & Units

| Parameter | Symbol | Dimension | SI Units | English Units |
|---|---|---|---|---|
| air space ratio | $G_a$ | (Dimensionless) --- | --- | --- |
| average interstitial velocity | $\bar{v}_i$ | $LT^{-1}$ | m/s | ft/s |
| capillary head, capillary rise | $h_c$ | L | cm | in |
| cation exchange capacity | CEC | charge $M^{-1}$ | (meq/100g)* | --- |
| centrifuge moisture equivalent | $w_c$ | --- | --- | --- |
| coefficient of hydrodynamic dispersion | (see dispersion coefficient) | | | |
| coefficient of mechanical diffusion | $D_m$ | $L^2T^{-1}$ | $m^2/s$ | $ft^2/s$ |
| coefficient of molecular diffusion | $D^*$ | $L^2T^{-1}$ | $m^2/s$ | $ft^2/s$ |
| coefficient of permeability | (see permeability) | | | |
| conductivity, effective hydraulic | $\bar{\bar{K}}_e$ | $LT^{-1}$ | m/s | ft/day |
| conductivity, hydraulic | $\bar{\bar{K}}$ | $LT^{-1}$ | m/s | ft/day |
| dispersion coefficient | $D_\alpha$ | $L^2T^{-1}$ | $m^2/s$ | $ft^2/s$ |
| diffusivity, soil water | D | $L^2T^{-1}$ | $m^2/s$ | $ft^2/s$ |
| dispersivity | $\alpha$ | L | m | ft |
| discharge velocity | (see specific discharge) | | | |
| distribution coefficient | Kd | $M^{-1}L^3$ | $m^3/kg$ | $ft^3/lb$ |
| drawdown | s | L | m | ft |
| effective hydraulic conductivity (see conductivity, effective hydraulic) | | | | |

* standard units used.



DRAFT

Table 1. List of Parameters, Their Symbols & Units (continued)

| Parameter | Symbol | Dimensionless Units | SI Units | English Units |
| --- | --- | --- | --- | --- |
| exchange capacity | EC | charge $M^{-1}$ | (meq/g) | --- |
| effective porosity | $n_e$ | --- | --- | --- |
| fluid potential | $\phi$ | $L^2T^{-2}$ | $m^2/s^2$ | $ft^2/s^2$ |
| flux | (see specific discharge) | | | |
| gravitational head | Hg | L | m | ft |
| ground-water flow (total discharge, or total flux) | Q | $L^3T^{-1}$ | $m^3/s$ | gal/day $ft^3$/day |
| head, elevation | $h_e$ | L | m | ft |
| head, pressure | $h_p$ | L | m | ft |
| head, static | h | L | m | ft |
| head, total | H | L | m | ft |
| hydraulic conductivity (see conductivity, hydraulic) | | | | |
| hydraulic diffusivity | T/S or $K/S_s$ | $L^2T^{-1}$ | $m^2/s$ | $ft^2/s$ |
| hydraulic gradient | I | --- | --- | --- |
| hydraulic head | H | L | m | ft |
| matric potential | $\Psi m$ | L | m | in. |
| moisture content (moisture equivalent) | w | -- | -- | -- |
| permeability | $\bar{\bar{k}}$ | $LT^{-1}$ | m/s | ft/day |
| permeability, intrinsic | $\bar{\bar{k}}_i$ | $L^2$ | $m^2$ | $ft^2$ |
| pore velocity | (see average interstitial velocity) | | | |
| porosity | n | -- | -- | -- |
| porosity, effective | $n_e$ | -- | -- | -- |
| potential drop | $\Delta h$ | L | m | ft |



DRAFT

Table 1. List of Parameters, Their Symbols & Units (continued)

| Parameter | Symbol | Dimensionless Units | SI Units | English Units |
| --- | --- | --- | --- | --- |
| pressure head | (see head, pressure) | | | |
| pressure, static | p | $ML^{-1}T^{-2}$ | Pascal | $lb/in^2$ |
| seepage velocity | (see specific discharge) | | | |
| specific capacity | $C_s$ | $L^2T^{-1}$ | $m^2/s$ | $ft^2/s$ $ft^3/ft/s$ |
| specific discharge (specific flux) | q | $LT^{-1}$ | m/s | ft/s |
| specific retention | $S_r$ | -- | -- | -- |
| specific storage | $S_s$ | $L^{-1}$ | $m^{-1}$ | $ft^{-1}$ |
| specific yield | Sy | -- | -- | -- |
| storage coefficient | S | -- | -- | -- |
| stress, neutral (pore pressure, pore water pressure) | $u_w$ | $ML^{-1}T^{-2}$ | $N/m^2$ | $lb/ft^2$ |
| Transmissivity | T | $L^2T^{-1}$ | $m^2/s$ | $ft^2/day$ |
| velocity, average interstial | $\bar{v}i$ | $LT^{-1}$ | m/s | ft/s |
| void ratio | e | --- | --- | --- |